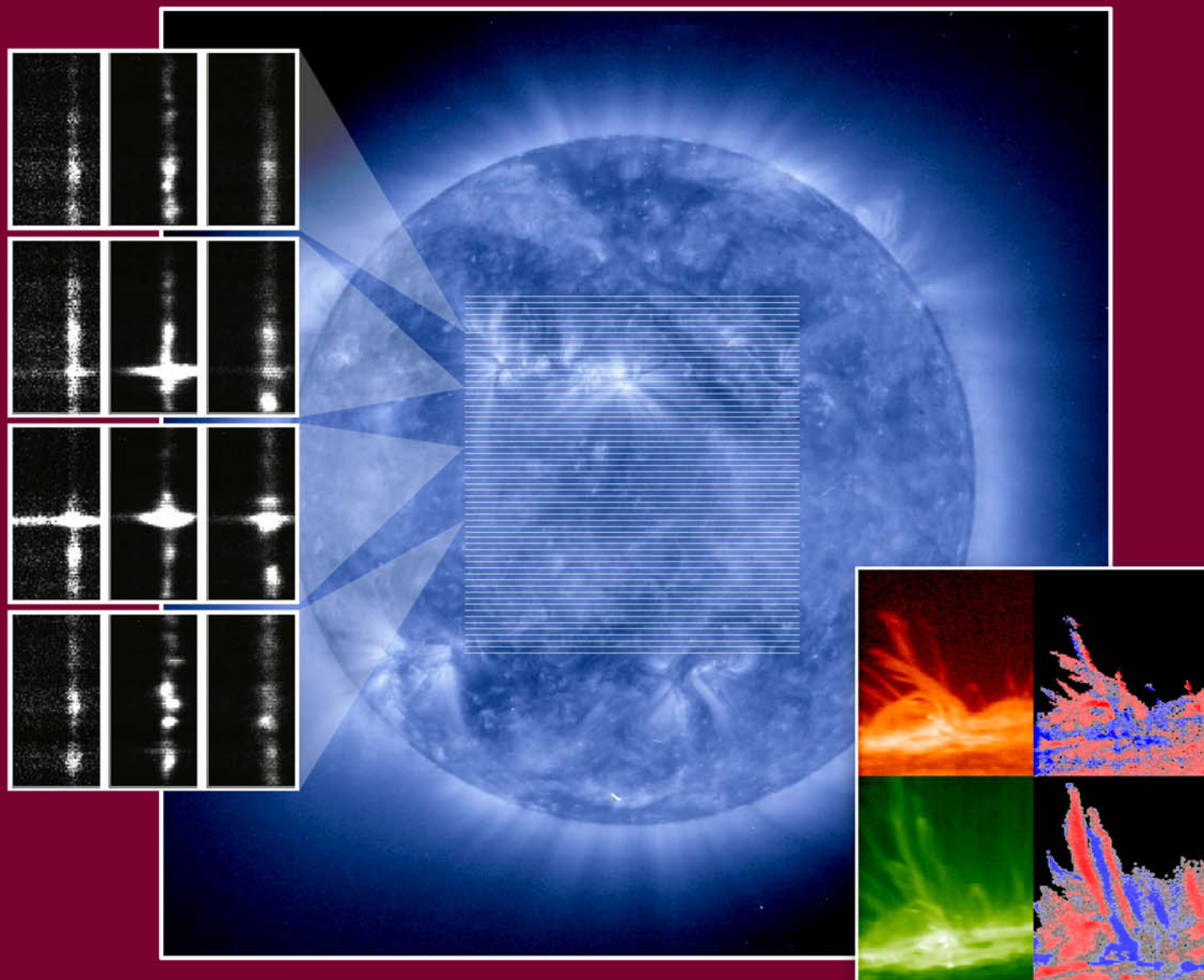# Atmospheric Imaging Spectrograph (AIS) for the Solar Dynamics Observatory

Submitted to the National Aeronautics and Space Administration in response to AO 02-OSS-01

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A.1 Executive Summary

The physics of space weather is the physics of energy storage, release, transport and deposition. The goal of the International Living With a Star (ILWS) program is to "develop the scientific understanding necessary to effectively address those aspects of the connected Sun-Earth system that directly affect life and society." To do this, we must understand the physical processes of the steady and transient phenomena that influence the space environment at Earth.

The AIS (Atmospheric Imaging Spectrograph) is a complete science investigation designed to address these goals. AIS will provide *quantitative* diagnostics to complement the other SDO instruments and enable complete, *quantitative modeling of the physical systems* that drive space weather. Highly leveraged with strong European participation, AIS provides outstanding science and value within the stringent fiscal constraints of the SDO mission. A summary of the AIS instrument characteristics is shown in Table A1-1.

Spectroscopic observations are essential if we are to understand solar dynamics and eruptions. However, the true test of understanding is the ability to model and predict. Critical parameters needed to constrain physical models are: velocity (both transverse and line of sight), rotational motions, non thermal broadenings (indicative of wave motion), electron density, and elemental abundances. Quantitative values for these parameters *cannot* be provided by imaging alone. For example, reconnecting plasma is not necessarily in thermal equilibrium, skewing temperature and density inferred from imaging instruments; and wave phenomena often confuse measurements of motions in image sequences. Spectroscopic observations are the only means of reliably measuring these parameters.

It is for these reasons that AIS is *required* for scientific closure on 5 out of the 7 over-arching scientific questions listed in the Executive Summary of the SDO Science Definition Team Report (see Table A1-2). AIS is central to the ILWS program objective of "targeted basic research" to understand the physical structures and mechanisms responsible for the solar variations that influence life on Earth. In fact, we will demonstrate in this proposal that *AIS exemplifies the philosophy of targeted basic research*, and is

Table A1-1. AIS Instrument Summary	
High resolution, large FOV, rapid scanning spectrograph with 3 simultaneous passbands above and below the Ly-continuum, with complete temp. coverage from low chrom. to flaring corona.	
Instrument Parameter	**Characteristics**
Type	Gregorian telescope, Spherical VLS grating spectrograph
Telescope Geometric Area	388 cm^2
Wavelength Coverage	1020-1130 Å (510-565 Å) 1150-1260 Å (575-630 Å) 1442-1552 Å (721-776 Å) 1500-1600 Å (Slit Jaw Camera)
Entrance Slits	Single 1" x 16' slit Dual 1" x 16' slit (15" spacing) + 2 calibration slits
Standard Obs. Mode	15' x 16' raster scan at 36 sec. cadence (continuous) + 4 Full Sun rasters per day
Detectors (3)	ICCD (2k x 4k - frame transfer)
Spatial Scale	0.65" pixel^{-1} (17 μm pixel)
Spectral Scale	68 mÅ/pixel (34 mÅ/pixel)
Spectral Resolution	16,000-24,000 (1 pixel) ~40,000 (w/ centroiding)
Velocity Scale	~17 km/s per pixel at 1200 Å
Velocity Resolution	+/- 2 km/s (w/ centroiding)
Dynamic Range	10^4 (10^8 w/ auto-ranging)
Slit Jaw Camera	CCD (2k x 4k - frame transfer)
FOV/Spatial Resolution	4' x 16' / 0.65" pixels

uniquely suited to achieve the following targeted ILWS research goals: 1) significantly advance the prospects for predictive space weather models, 2) provide likely candidates for *new* precursors and direct detection of imminent CME liftoff, 3) identify the evolving boundary condition for the solar wind important to understanding the structure of the inner heliosphere, and 4) understand the link between solar activity, solar spectral radiance distributions, and solar spectral irradiance.

Not only is AIS an essential instrument for SDO, but SDO is the essential platform for AIS. The AIS optical design and observing strategy have been optimized to exploit the high, continuous telemetry rate afforded SDO, maximizing synergy with other key instruments. It also embraces the SDO mission philosophy of hands-free operation, producing a synoptic data base that can be accessed as easily in real time as through the archive.

The AIS synoptic capability is enabled not only by the high continuous telemetry rate of SDO, but by two innovative design aspects: 1) dual slit spectral windowing, and 2) "echelle" mode rastering (§A.2.8). As a result, AIS is capable of

Table A1-2: AIS is *required* to fully address five of the seven ILWS SDO primary science questions outlined in the Executive Summary of the SDO SDT Report. *Only HMI and AIA are required as frequently.*

SDO Science Definition Team Report: Executive Summary Science Questions	Physical Observables	Measurements Required	Instr. Required
1. What mechanisms drive the quasi-periodic 11-year cycle of solar activity?	Time series obs. of global subsurface flows. Spatially resolved time series of photospheric magnetic flux over solar cycle.	Full disk helioseismic Dopplergrams, magnetograms.	HMI
2. How is active region magnetic flux synthesized, concentrated, and dispersed across the solar surface?	Time series obs. of global subsurface flows. Spatially resolved time series of photospheric magnetic flux over solar cycle.	Full disk helioseismic Dopplergrams, magnetograms, Atmospheric images.	HMI AIA
3. How does magnetic reconnection on small scales reorganize large-scale field topology and current systems? How significant is it in heating corona and accelerating solar wind?	Quantitative time resolved observations of density, temperature, bulk flow, wave motion and magnetic flux from the photosphere to the corona.	Atmospheric images, magneto-grams, UV/EUV spectra (intensity, line shift, line width) from all heights in solar atmosphere.	AIS AIA HMI
4. Where do observed variations in Sun's total and spectral irradiance arise, how do they relate to the magnetic activity cycles?	Time series of spectrally resolved EUV irradiance. Full disk spatial & spectrally resolved time series of EUV radiances and magnetic flux.	Synoptic, full disk EUV irradiance spectra. Synoptic, full disk, spatially resolved EUV radiance spectra, magnetograms.	AIS AIA SIE HMI
5. What magnetic field configurations lead to CMEs, filament eruptions, and flares that produce energetic particles and radiation?	Quantitative time resolved observations of density, temp., bulk flow and magnetic flux of ARs, CMEs, filament eruptions and flares, from photosphere to corona.	Atmospheric images, magneto-grams, UV/EUV spectra (intensity, line shift, line width), coronagraphic images.	AIS *AIA HMI WCI*
6. Can structure and dynamics of solar wind near Earth be determined from magnetic field config. and atmospheric structure near the solar surface?	Quantitative time resolved observations of density, temp., bulk flow and magnetic flux from photosphere to corona and into solar wind.	Atmospheric images, magneto-grams, UV/EUV spectra (intensity, line shift, line width), coronagraphic images.	AIS *AIA HMI WCI*
7. When will activity occur, and is it possible to make accurate and reliable forecasts of space weather and climate?	Quantitative time resolved observations of density, temp., bulk flow and magnetic flux of ARs, CMEs, filament eruptions and flares, from photosphere to corona.	Atmospheric images, magneto-grams, UV/EUV spectra (intensity, line shift, line width), coronagraphic images.	AIS *AIA HMI WCI*

performing synoptic spectral imaging over a large field of view (15' x 16') with high time cadence (36 sec), two orders of magnitude (100X) faster than existing or proposed spectrographs (Figure FO1-1). These high time cadence, large FOV synoptic observations permit AIS to address a completely new league of scientific questions and problems, such as cross-scale and rapid phenomena that are inaccessible to other spectrographs.

The AIS investigation has been designed to complement ideally both the SDO/AIA imaging package and the SDO/SIE full disk irradiance experiment. AIS will address and resolve interpretational ambiguities seen in the imaging data and will cover temperature and height ranges critical to linking coronal observations with the lower atmosphere, but not observed with AIA or SOLAR-B/EIS. AIS is also the only investigation capable of providing high spatial resolution, monochromatic radiance observations necessary to fully model and understand the sources of irradiance variability seen with SIE.

AIS will operate in a standard, fixed, synoptic observing mode to minimize operations complexity. The data pipeline of reduction, software analysis tools and archiving has also been streamlined and will be coordinated with AIA, HMI and SIE to provide common, user-friendly visualization tools and easy access for spectroscopists and non-spectroscopists alike! This unprecedented accessibility will be achieved because the AIS science team includes both members with decades of experience in analyzing spectrographic data and experts in the development of visualization tools for scientific analysis. AIS data products include powerful 4D spectroheliograms (x, y, λ, t), as well as time series images (movies) of emission line intensity, line width, and line-of-sight velocity (Dopplergrams).

The AIS team experience and emphasis on accessibility is also reflected in our strong commitment to E/PO, leveraging existing resources to achieve international impact.

The AIS instrument team, led by Southwest Research Institute (SwRI), has extensive experience designing, building and flying space instrumentation, including many of the instruments on SOHO (SUMER, CDS, UVCS, MDI), TRACE, and the IMAGE MIDEX mission. Moreover, the AIS management team has decades of experience in managing projects that include a significant number of international partnerships (most recently IMAGE, with 5 international partners). Our international AIS team maximizes NASA resources with highly leveraged hardware, data analysis software, and science contributions from our European partners of more than 1/2 the total investigation cost, or roughly $35 million. Together, the AIS team provides a simple, yet sophisticated and essential component of the SDO mission at an affordable cost to NASA.

A.2   Scientific Goals and Objectives

AIS is designed to address the specific scientific goals outlined in the SDO SDT report, while operating within the "hands-off" operational paradigm of the SDO mission and adding significant new science at low cost to NASA.

AIS is optimized for the time-resolved, spectral imaging, and plasma diagnostic measurements that are needed to address the applied science questions that SDO is meant to answer.   In the following sections, we demonstrate how AIS is essential to the goals of the SDO mission.

A.2.1   The "Magnetic" Transition Zone
[SDT Questions 3,4,5; Standard observing mode]

AIS will, by observing spectral features simultaneously from 510 to 1560 Å (Figure FO1-2), provide data from just 500 km above the visible photosphere into the corona.   Radiation near 1580 Å originates from 300 km (two pressure scale heights) above the formation of photospheric lines that will be observed by HMI, and overlaps with wavelengths near 1600 Å that might be chosen for the AIA instrument.   Observing continua and lines that encompass the entire solar atmosphere from the low chromosphere into the flaring corona near 10 MK, *AIS provides SDO with a complete spectral link between the core HMI and AIA instruments*.

This link is much more than a way to fill an "observational gap" in the SDO mission.   The 2000 km or more vertical distance between the photosphere and the corona, although geometrically small, spans 14 pressure scale heights.   The character of the plasma changes dramatically between the photosphere and corona: the magnetic field morphology changes from flux tube to space-filling within the chromosphere.   It is therefore not surprising that tracing observable physical links between photosphere and corona has proven extremely difficult (Figure A2-1).   The chromosphere spans a physical "frontier" which separates the $\beta \gg 1$ deep photosphere, where turbulent fluid flows control the dynamics of the embedded field lines, from the $\beta \ll 1$ transition region and corona, where the field entrains the gas and guides its motions. The $\beta \sim 1$ regions are places where MHD wave mode conversion is expected to be strong.   Recent work has shown how mode conversion (Kudoh & Shibata 1999) and magnetic field fragmentation (Sakai & Furusawa 2002) near the $\beta \sim 1$ level within the chromosphere can

completely change the lower boundary conditions for the coronal magnetic field and plasma. Hence we use the phrase "magnetic transition zone" to describe these critical $\beta \sim 1$ layers.

The entire region is important for many additional reasons: it supplies mass, momentum and energy for the corona; it is the region of the atmosphere where the FIP effect operates; its UV irradiance far exceeds that of the overlying layers and powers the heating of the earth's thermosphere; and it mediates the solar wind mass flux (Leer, Hansteen, & Holzer 1997).   Although recent theoretical work has re-emphasized the importance of thermodynamic coupling between the chromosphere and corona (Athay 2000) these layers remain largely unexplored.   Instruments on SOHO have made progress but are limited by the lack of complete spectral coverage of the entire atmosphere.   Planned future missions will miss this region entirely (e.g. the EIS on Solar-B) and lack sufficient simultaneous FOV and temporal resolution to capture the important dynamics (e.g. ASCE; see Figure FO1-1).   The magnetic transition zone is also not well covered by AIA. Because these issues lie at the heart of the physics of energy supply, propagation, and dissipation throughout the solar atmosphere, and because the
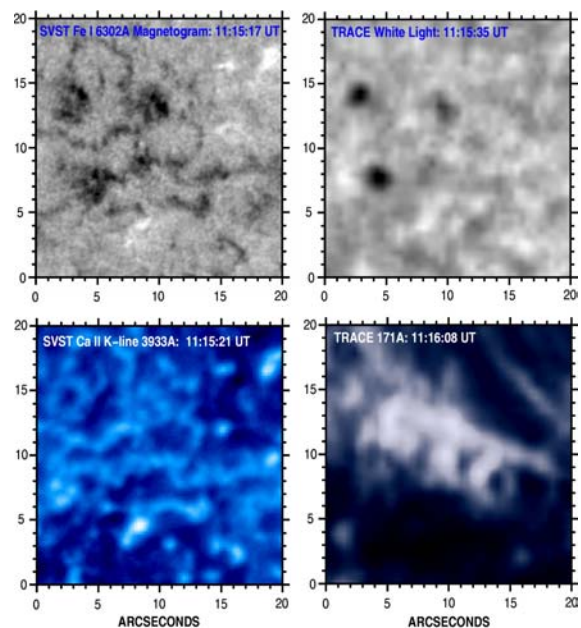

Figure A2-1.   Four simultaneous views of the same solar feature, showing the lack of correlation between heating and brightness on small scales in the chromosphere and corona.   The chromospheric features do not correspond to the footpoints of the coronal structures. (Berger *et al.*1999)

energy dissipated in and radiated by the chromosphere dominates much of the variable UV irradiance, the SDO mission simply cannot afford to leave this region unexplored. *Only with AIS is SDO able to address the structure and dynamics of the chromosphere and magnetic transition zone.*

A.2.2   Physics of Active Regions and Flares
[SDT Questions 5,6,7; Standard observing mode]

AIS observations of flow, heating, and wave motion in active regions are critical in two important ways to our understanding of these important flux systems and the causes of solar flares. Moreover, AIS observations of the Fe XVII 1153 Å line formed at temperatures characteristic of AR material will complement ideally the passbands of the AIA proposed by LMSAL.

Active Region Loop Dynamics. Bulk kinetic energy dominates gas thermal energy in active region loops (Brekke *et al.* 1997; Winebarger *et al.* 2002). TRACE and EIT (at 1-1.5 MK) show emission fronts moving along the magnetic fields, while Doppler shifts of EUV lines observed with CDS and SUMER show typical LOS speeds of ~40 km/s (Figure A2-2). The variation of velocity with position is inconsistent with simple siphon flow, and a variable component changes in tens of seconds. Imaging instruments such as TRACE or AIA can detect moving emission fronts but not steady flow, missing the largest non-magnetic reservoir of energy in the system. *AIS will provide high cadence two-dimensional spectral images (Dopplergrams) to quantify these flows.*
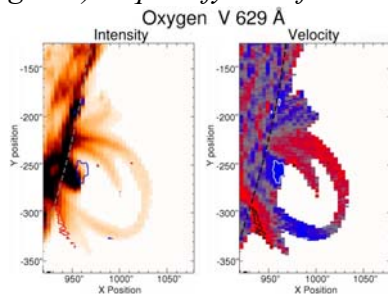

Figure A2-2. CDS images of intensity and Doppler shift showing draining of an active-region loop. With 4x smaller pixels and 36 second time resolution, AIS will identify reconnection sites, jets, counterstreaming flows, temperature distributions, and wave motion in active region loops.

CDS and SUMER observations of a sunspot (Brynildsen *et al.* 1998) demonstrate that the active region flow field in the low corona is markedly different from that in the transition region. In transition region emission (250,000 K) there are

upflows in the umbra and downflows in much of the penumbra of a sunspot (Figure A2-3). Higher up in the upper transition region and low corona, the plasma above the sunspot all moves downward. The spectroheliogram in Figure A2-3 is limited in spectral coverage and required 20 minutes to assemble. AIS dense scans will accumulate larger fields at higher resolution with more complete spectral coverage in under 1 minute, revealing the velocity structure from the chromosphere to the corona simultaneously.
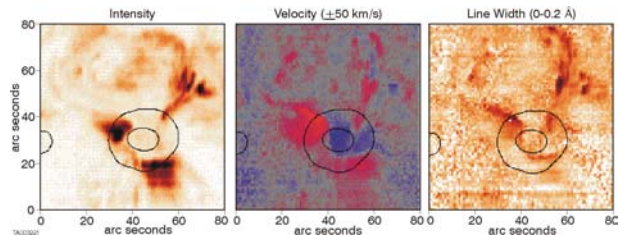
Figure A2-3. SUMER O V 629Å spectral images over a sunspot, showing redshifts in the bright loops and blueshifts above the umbra (inner countour). Only 2 of the 3 anchored in the penumbra (outer contour) show enhanced line broadening.

AIS measurements of active region loop oscillations will allow determination of the coronal viscosity and Alfvén speed throughout the loop structures in active regions, the chromosphere, and the corona; these parameters are currently unknown and are critical to understanding coronal evolution and heating. TRACE image sequences have detected postflare trapped Alfvén waves with displacement amplitudes above several thousand kilometers and periods as low as 100 seconds (e.g., Schrijver *et al.* 2002). More recently, Fe XXI Doppler shift observations of a post-flare loop with SUMER, observing at a fixed position in the corona, have recorded longer period Doppler shift oscillations in hot flare lines (Innes *et al.* 2001; Figure A2-4). Alfvén oscillations are a powerful tool for diagnosing plasma *in situ*. Measurements of the decay rate have been used to estimate the effective viscosity of the solar corona (Ofman *et al.* 1999). AIS will detect similar transverse waves by direct Doppler shift at amplitudes as low as 15 km and periods as short as 3 seconds, extending the frontier of knowledge by 1.5 orders of magnitude in both the amplitude and frequency domains and enabling measurement of resonances in smaller loops in nonflare environments.

Magnetic Reconnection in Active Regions and Flares. During solar flares, extremely high

Figure A2-4. Doppler-shift oscillations in Fe XXI 1354 Å seen with SUMER from a hot loop top. (a) EIT image of the AR shows the position of the SUMER slit, marked as a thin vertical white line. The position of the loop brightening is indicated by a horizontal tick mark on the SUMER slit. (b) Doppler-shift time series of the Fe XXI line. (c) Average Doppler-shift time profile along the slit in (b). The black solid curve is the best-fit damped sine function. (Innes *et al.* 2001)
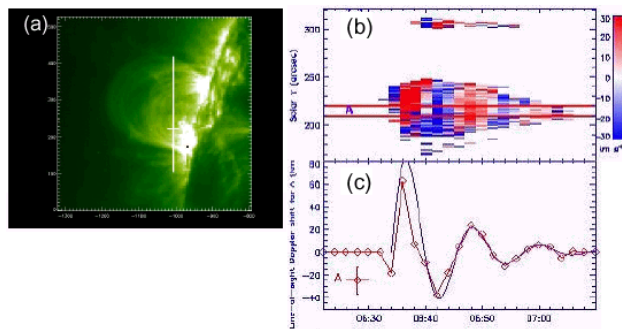
temperature lines outshine lower temperature emissions in the corona. High temperature emissions have been explored so little with spectrally resolved imagers with high spatial resolution, that it is difficult to predict where the main discoveries will be; but one obvious target is the temperature and flow in the bright, magnetic, soft X-ray emission structures that drive flare energy release. The early stages of the flare are characterized by large non-thermal broadenings and blue-shifted X-ray emission. These flare precursors were tracked with SMM-UVSP (Mason *et al.* 1986), where blue shifts in excess of 200 km/sec were correlated with impulsive chromospheric brightenings at the footpoints of large loop structures. The limited ability of SOHO/SUMER to either raster or view flares has precluded such observations from being repeated.

Most recently, RHESSI has found clear evidence for pre-flare acceleration of non-thermal particles (Lin 2002). Bursts of HXR radiation, preceding the main impulsive phase of the flare by a few minutes, were observed simultaneously with Radio Type III bursts from relativistic electrons. These observations, together with the recently reported BATSE observations of copious non-thermal X-rays above 25 keV in even the smallest B and C flare events (Lin *et al.* 2001) strongly suggest that particle acceleration by high-altitude reconnection is ubiquitous in flarelike events; these hard X-ray events may be caused by the same particle impacts that were seen with SMM; if so,

they should be coincident with brightenings both at high temperature and in the transition region. *AIS is specifically designed to be able to observe active region and flare plasmas at high emission in both the corona and the cooler transition region and chromosphere, to identify the location of flare-triggering reconnection.*

A.2.3 Understanding and Predicting Solar Activity and Space Weather

[SDT Questions 5,6,7; Standard observing mode]

Understanding the physics of the solar atmosphere is only half of the overall SDO mission plan. SDO will also prototype future operational systems for predicting solar transient events and space weather. Successful space weather forecasting entails reliable characterization of impulsive solar disturbances as well as accurate knowledge of the global corona and solar wind through which they propagate toward Earth. *AIS observations will significantly improve understanding and prediction of CME-related space weather for two reasons: spectral imaging data are the most likely new candidate for direct on-disk detection of imminent CME liftoff; and spectral signatures are required to understand the release process and early propagation of CMEs.*

Models of CMEs and Flares. Current understanding of coronal stability is not sufficient to predict flares or CMEs. Both systems are thought to be driven by magnetic energy release, but neither the stabilizing mechanism allowing energy to accumulate, nor the release process are understood well enough to predict eruption reliably. Existing models of eruptions include reconnective cascades (Moore *et al.* 2001), large scale reconnection (Aulanier *et al.* 2000), destabilization by flux emergence, draining of matter from structures overlying a filament (Fan 2002), and smooth loss of magnetic equilibrium.

Spatiotemporal differences in chromospheric and transition-region line width and Doppler shift are strong discriminators between these models. For example, the classic reconnective flare/CME system (Figure A2-5) gives rise to large reconnective jets at the legs of the erupting structure and strong line broadening at the footpoints. Modern variants such as "tether cutting" and "breakout" require different morphologies that can be readily distinguished by spatially resolved chromospheric and coronal Doppler signals. Similarly, quiescent filament
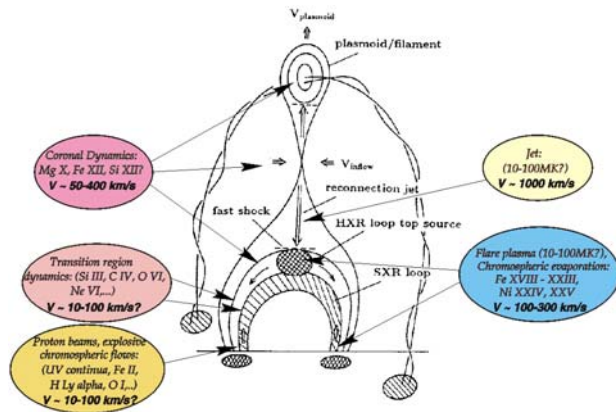
Figure A2-5. Cartoon depicting a solar flare model. (Shibata 1997)

Figure A2-6. An X-2 flare spray ejection observed by CDS (Pike & Mason 2002). The vertical white bar marks zero radial speed and a shorter line marks a blue shift of 400 km/s. The spectral line profiles show helical structures unravelling as they shoot out from the flare site.

eruptions can release several times the Aly-Sturrock conjectured maximum energy provided that even small amounts of magnetically supported mass drain first (Fan 2001), while some special flux topologies may allow even force-free fields to violate the Aly-Sturrock limit and erupt because of sudden loss of equilibrium (Weber 2002). Discriminating between these two models requires spatially resolved filament Doppler shift measurements in the minutes prior to eruption. *AIS time/space resolved measurements of Doppler shift and heating throughout the lower layers of the solar atmosphere will explore the critical, but unknown, conditions and physical mechanisms of flare and CME onset.*

It is undetermined how sheared magnetic fields in filaments are connected to those of CMEs and to general solar structure. It is also unclear how the field changes during eruption. High spatial and time resolution imaging coupled with Doppler information from both quiet and erupting filaments can reveal 3-D mass motions and thus the direction of the magnetic field. *Together with transverse motion determinations from AIA, AIS will identify the 3-D magnetic field structure within most Earth-directed CMEs during the SDO mission.*

For example, Pike & Mason (2002) reported the first spectroscopic observations of the eruption of a helical magnetic flux tube from an X-class flare, with an associated halo CME (Figure A2-6). CDS recorded a very high velocity ejection of plasma, seen in O V (2.5×10^5 K) emission. Spectral line profiles indicate a rotational motion of 350 km/s, showing that the material is traveling along a helical magnetic flux tube. Because of FOV limitations, only one such observation has been obtained in six years of *SOHO* operations.
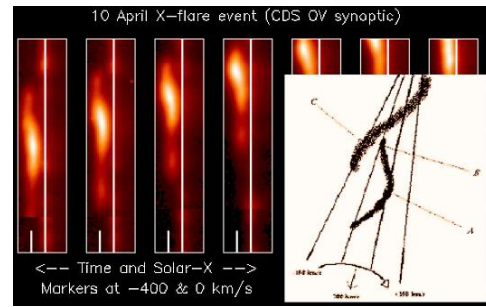
With AIS, such observations will be routine and easily accessible. The standard AIS observing mode FOV and cadence will enable the speed, direction, acceleration, and magnetic structure of most Earth-directed filament eruptions to be tracked throughout the lower corona.

The broad temperature coverage offered by AIS allows us to study, in new detail, the partition of energy in eruptive events, capturing detailed, time-resolved temperature portraits of the plasma surrounding each erupting filament (~10,000K to ~500,000K) and its surroundings (~10^6 K). Together with AIS Dopplergrams, this will allow us to determine the energy partition between heating, acceleration, and turbulence in each event. Understanding where and how energy is released in these different forms will allow us to better understand the physical systems associated with solar activity, and to better predict their interactions with the IMF and with Earth.

Precursors to Eruption. AIS will allow us to find new reliable precursors to filament eruptions (Figure A2-7). Existing indicators, such as magnetic field configuration (Falconer *et al.* 2002) and X-ray sigmoidal structure (Canfield *et al.* 1998), do not provide precise prediction of CME onset. Spectral signatures of CME onset are likely to prove more reliable and more robust than existing methods. Signatures that may be detectable up to hours before eruption include (Engvold *et al.* 2001) an early slow liftoff seen in Doppler shift, increased turbulent motions and/or heating, Lyman line asymmetries associated with prominence flows of 100 km/s or higher (Schmieder *et al.* 1998, 2000; Gontikakis *et al.* 1997), sudden downflows in the vicinity of a prominence due to mass draining or reconnection

Figure A2-7. Simplified cartoon adapted from Harrison (1986) showing possible timing of CMEs, flares, and potential event precursors. AIS's large FOV and high cadence enable a search for new CME precursors, which could greatly improve space weather forecasting.

(e.g. Fan *et al.* 2002), and sudden broadenings of chromospheric lines associated with energetic particle impacts due to reconnection high over the site of the potential eruption.

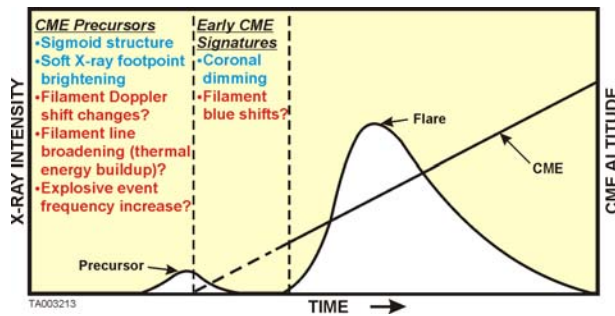**Toward a Predictive Capability.** At present, the best indicators of oncoming geoeffective coronal disturbances are morphological: visible halo CME events, type II radio bursts, large flares, disappearing filaments, coronal dimmings, and "EIT waves". Although coronagraph image sequences in principle provide some velocity information, they cannot measure directly the speed of Earth-directed shock fronts. *AIS Doppler images offer the possibility of such observations*.

AIS will provide two types of signature information that have special relevance to future space weather modeling: those that are indicative of incipient activity (precursors), and those providing direct quantitative information on eruptions actually underway ("nowcasting"). Measurements of motions and changes in nonthermal velocity distributions in the lower corona and chromosphere are crucial to understanding the structure of the inner heliosphere, and for separating the various models of CME onset. Depending upon the specific physical process, AIS Dopplergrams and other derived data products are likely to be the most reliable indicators that a specific region is about to erupt. Even without advance warnings, the reliable characterization of near disk-center CME liftoff by means of AIS Doppler imaging represents a significant improvement in space weather modeling capability.

We anticipate that AIS observations of the 1216 Å Lyman-α line may be an especially sensitive indicator of filament dynamics, simply

because the line is so opaque (See Figure A2-8). Earlier observations are limited (i) because absorption components have been washed out by continuum emission in images taken through broad bandpass filters, (ii) because of contamination issues (now understood) in previous instruments, and/or (iii) because the line was too intense for earlier detectors. *With our choice of a fixed grating, a specially tailored detector with a large intrinsic dynamic range and attenuating mesh mask, and careful prelaunch and on-orbit contamination control, observations of H Lyman-α will be routine for AIS.* We will develop automated analysis techniques for this important, optically thick line in addition to the moment analysis used for our other, simpler lines (see §A2.6).
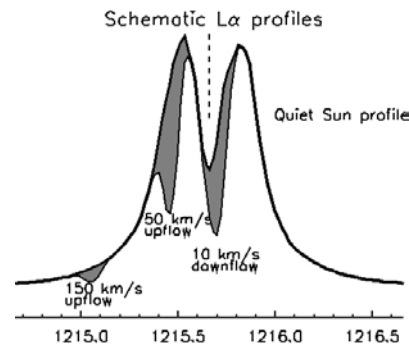
Figure A2-8. Lyman α 1216 Å with and without Doppler-shifted prominence absorption. Routine Lyman α measurements by AIS have the potential to track CMEs even more effectively than simpler lines such as He 584 Å.

Figure A2-9 simulates the observational signature of a filament/CME eruption seen in He I 584 Å with AIS. These Doppler and line width data will not only assist us in identifying potential new precursor signatures, but will improve physical models and understanding by characterizing the bulk and internal kinetic energy and internal morphology of Earth-directed CMEs as they leave the lower corona and accelerate toward Earth. These inputs, together with interplanetary MHD models and observations from AIA, HMI, and WCI, will enable fundamental improvements in physics-based forecasting of event geoeffectiveness.

A.2.4 Boundary Conditions for the Solar Wind and Space Environment

[SDT Questions 6,7; Standard observing mode]
Synoptic spectral imaging with AIS will allow direct probing into the physics and changing
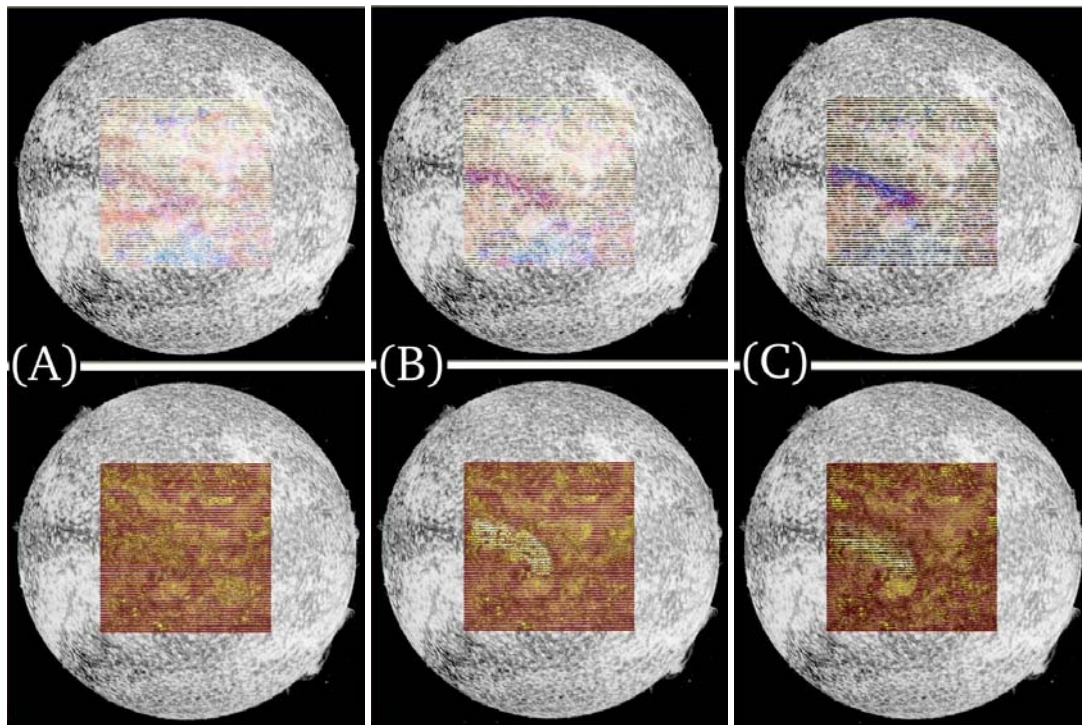
(Ly α image: Stanford/MSSTA, 1991)

Figure A2-9. AIS data products will show precursors and quantitative kinetic energy for virtually every Earth-directed CME during normal observing mode. TOP: AIA + AIS He 584 Å Doppler; BOTTOM: AIA + AIS He 584 Å line width. (A) Quiet Sun with quiescent prominence; (B) 30-60 min. prior to liftoff, draining motions and reconnection yield Doppler and line-width signatures; (C) 15-30 min. after liftoff, AIS captures quantitative acceleration and turbulent-motion profiles. *AIS lines encompass temperatures between $10^{3.7}$ and 10^{7} K; actual data will include similar products for coronal and flare lines.*

shape of the solar wind source region, allowing solar-driven models of the solar wind in the acceleration region, inner heliosphere, and near-Earth environment.

Understanding and predicting the solar wind behavior near Earth requires knowledge both of the physics of wind propagation through the inner heliosphere, and of the wind's source region and acceleration mechanism in the solar atmosphere. Determining the physics and structure of the wind's acceleration requires tracing the outflowing plasma from the solar surface, through the chromosphere and transition region, to the corona. Imaging spectroscopic studies using SOHO/SUMER have demonstrated that Dopplergrams of chromospheric and coronal spectral lines can trace the origins of the solar wind (Hassler *et al.* 1999).

Source Region of the Nascent Solar Wind. *AIS full disk synoptic Dopplergrams will image the size, shape, and velocity structure of the solar wind coming from coronal holes as a function of time, providing critical boundary conditions for coronal and solar wind models.* The SUMER Ne VIII

Dopplergrams in Figure A2-10 show differing velocity structure in polar and equatorial coronal holes, consistent with recent UVCS results (Mirales *et al.* 2001). However, these SUMER observations were not made on a regular basis and required eight hours to produce. AIS will create complete full sun synoptic scans over a wider temperature range in only 20 minutes, once every six hours throughout the SDO mission.

Radial velocities in the polar coronal hole in Figure A2-10 range from 5-12 km/s, whereas radial velocities in the equatorial coronal hole are on the order of 3-8 km/s, almost a factor of two lower (Buchlin & Hassler, 2000). Outflow occurs predominantly on network boundaries and their intersections. There is no clear correlation between velocity and intensity within the network, suggesting that energy either heats local closed structures or accelerates material but not both. Empirical studies and models (Wang & Sheeley 1990; Suess *et al.* 1997) suggest that flow speed is related to the degree of expansion of magnetic flux tubes close to the Sun (see Figure A2-11). Highest (lowest) flow speeds occur where the expansion
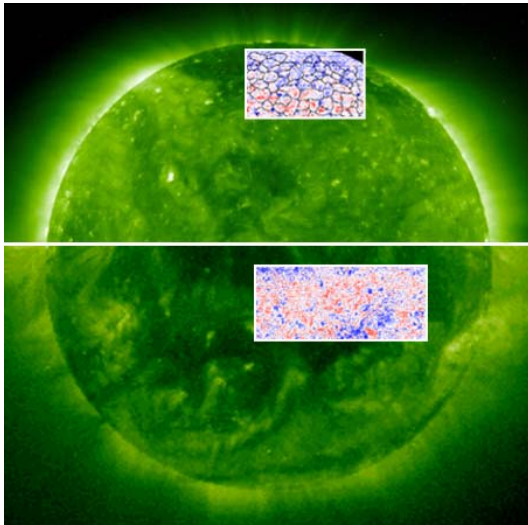
Figure A2-10. SUMER Ne VIII Dopplergrams showing outflow velocity structure in both a polar and equatorial coronal hole in Sept. 1996 and Nov. 1999, respectively (Hassler *et al.* 1999, 2001).
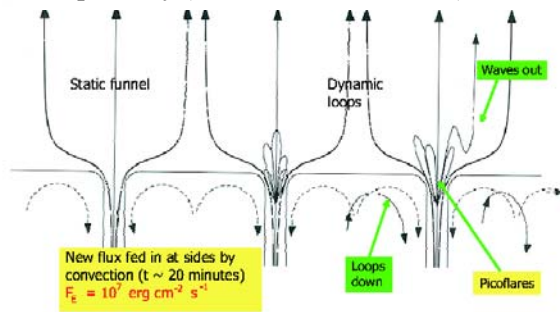

Figure A2-11. The dynamic magnetic network: funnels, loops and picoflares. (Tu & Marsch 1995)

factor is smallest (largest*). The strong blueshifts seen along network boundaries suggest that these regions may be the only places where the magnetic field is open, highlighting the relationship between field strength, overlying morphology, and plasma acceleration. *All three of AIS, AIA, and HMI are required to understand the relationship between energy deposition, magnetic morphology, and wind outflow throughout the solar cycle.*

Heating of the Corona and Source of the Solar Wind. The structure of the chromospheric network is similar beneath the closed, quiet corona and open coronal holes; it is the overlying structures that differ. The heating mechanisms that can work in the simple magnetic topology of coronal holes are a strict subset of the mechanisms available in the more complex corona. *Identifying the low-altitude energy source for the high-speed solar wind is a major, and required, step toward explaining the heating of the corona.*

Doppler dimming results from SOHO/UVCS suggest indirectly that the fast solar wind is accelerated rapidly (in the first solar radius above the surface) and that it is driven by ion-cyclotron resonant Alfvén or other waves in the lower corona (e.g. Kohl *et al.* 1997; Wilhelm *et al.* 1998; Tu *et al.* 1998). In the low-β, open-field plasma of the coronal hole, all flux tubes have approximately the same morphology, so the difference between the slow wind in polar plumes and fast wind in interplume flux tubes must lie in the location and nature of the energy input to the two types of feature (e.g., DeForest *et al.* 2001; Cranmer *et al.* 1999; Wang 1994). *The 16' length and E-W orientation of the AIS entrance slit, together with low scattered light and large effective area, will enable AIS to explore the heart of the solar wind subsonic accleration region out to 1.6 solar radii in polar coronal holes and at the coronal hole/streamer interface.*

Solar Wind Variability. AIS measurements of the input to the ambient solar wind are a crucial ingredient in space weather prediction. Space weather effects at Earth are strongly affected by the spiral structure of the inner heliosphere, which is itself shaped by the flow of the ambient solar wind. The interplanetary magnetic field channels energetic solar particle bursts, giving source regions near the western solar limb good access to Earth. Even in the absence of CMEs, differing solar wind domains and the corotating interaction regions (CIR) that form between them can produce shocks and variation in bow pressure on Earth's magnetosphere (e.g. Zirker 1977); but, more importantly, CIRs can greatly enhance the impact of CMEs on the Earth (Crooker *et al.* 1999*).* Furthermore, CME arrival time depends sensitively on the speed and structure of the intervening solar wind (Gopalswamy *et al.* 2001). Understanding the development of CIRs and shocked regions in the solar wind requires modeling the IMF and ambient wind from its source to beyond 1 A.U.

Currently, models of the large-scale coronal magnetic structure and global solar wind flow are driven entirely by synoptic observations of the solar photospheric field (e.g., Wang & Sheeley 1997; Riley, Linker & Mikic 2001). *By mapping and following the time-evolution of the solar wind source region, AIS will allow for the first time a rigorous coupling of interplanetary heliospheric phenomena to the solar surface; these*

measurements can be obtained in no other way than by long-term, time-resolved, spectral imaging in the FUV.

A.2.5 Sources of Spectral Irradiance Variability

[SDT Questions 2,4; Synoptic Full Disk mode]

Understanding the Sun's EUV spectral irradiance and variability requires not only irradiance time series but also spatially resolved radiance observations of solar features at all temperatures/formation heights simultaneously, to compare with radiative transfer models of the solar surface. Measurements are needed on at least two timescales: that of active region development (hours to weeks); and that of the solar cycle (years). *The AIS full-disk synoptic scans will yield the most consistent series of high-resolution UV/EUV spectroheliograms and Lyman-α images ever obtained, providing important input to radiative transfer models of the solar atmosphere and explaining irradiance phenomena that affect Earth's atmosphere.*

Spectral Irradiance, Space Weather, and Earth's Climate. Changes in solar UV brightness and spectrum affect the chemistry, dynamics and temperature of the Earth's outer atmosphere, affecting satellite drag and indirectly influencing the amount of energy absorbed by land and oceans. UV absorption leads to important processes including photoionization of N_2, O_2, NO, and O at wavelengths below 1300 Å, and is the main source of energy for ionization and heating of the ionosphere. Knowledge of the solar spectral irradiance is critical for understanding climate variability and for isolating external variations from human made and innate climate variability.

Whether the recently measured global warming trend is dominated by anthropogenic effects or has a significant or even dominant solar component is not yet known. Most current climate models only include direct solar forcing from changes in total solar irradiance. Variation in the proportional EUV irradiance is a significant effect, but is not accounted for because few measurements exist and solar proxy models are not yet sophisticated enough. *We will build on the AIS team's experience to develop physical models of UV/EUV irradiance, complementing the use of UV proxies to probe the solar spectrum over time and to understand Earth's global warming trend.*

Toward Predictive, Physical Models of Spectral Irradiance. Currently, most space environment modelers either use a "heuristic" (non-physics-based) model or a flux proxy, such as the F10.7 radio flux, and/or information about the surface magnetic structure. Comprehensive, physics-based models would predict solar variations and their effect on the Earth system more accurately because the relationship of existing proxies to the actual spectral irradiances is poorly quantified.

Physics-based solar spectral irradiance models are important both as predictors of total UV flux at Earth and as tools for understanding the physics of the stellar coronae and chromospheres (Fox *et al.* 1990, 2002). These models require several inputs, including observations with high spatial resolution (few arcsec), moderate temporal resolution (minutes to hours), and moderate spectral resolution ($\lambda/\Delta\lambda \sim 1000$; sufficient to resolve individual spectral features and continuum intensity), in order to measure radiance and variability of particular solar features. Solar features that contribute to irradiance variability include active regions and their remnants, the chromospheric network, faculae, plage, quiet sun, coronal holes, and filament channels. Each of these components is modeled separately. For example, sunspots have maximum effect near disk center while plage has the opposite spatial behavior and more complex spectral characteristics. To date, proxy measurements or approximations to the features have been used as input to irradiance models because no appropriate time-varying, spatially resolved UV data exist. *AIS will allow, for the first time, the simultaneous identification and realistic assessment of the contributions of each of these evolving activity features to total spectral irradiance.*

The SunRISE Model. *A sophisticated physics-based model, the SunRISE Spectral Irradiance Synthesis (Fontenla et al. 1999; Fox et al. 2002) was developed, in part, by AIS team members.* SunRISE is sophisticated enough to encompass AIS data, which are required to constrain it. SunRISE includes radiative transfer under LTE and non-LTE conditions, empirical solar atmospheric models, two-level and multi-level atoms, non-LTE ionization, line-by-line opacity contributions, variable spectral resolution, and anisotropic effects due to center-to-limb variations of solar features. It accounts for the

detailed center to limb variations of 70 separate solar feature components and produces calculations in physical units ready for direct comparison to observations. The SunRISE physical model uses as input empirical atmosphere models that are matched to radiance observations from the deep photosphere to the low corona.

Extending SunRISE into the EUV. SunRISE is currently being extended into the EUV, partly in response to requests for use in terrestrial atmospheric models (Bougher *et al.* 1999) and from the NOAA/SEC. *AIS will provide critical new observations that are needed to characterize detailed spectral radiance and time variability of structures in this new regime, and will be input into the extended SunRISE model.* Crucial AIS inputs to this model include spatiotemporal observations of He I at 584 Å, Lyman-α, Lyman-β, the Lyman C I and Si I continua, the C edge at 1100 Å, and the Si edge at 1526 Å. Experience from detailed UV line studies suggests that current measures of variability are strongly affected by spectral resolution, and *AIS will provide one of the first dedicated time series of high spatial and spectral resolution EUV variability.*

Variability and Contribution of Lyman-α. Lyman-α is by far the most intense solar emission line in the UV. It is the dominant component of FUV flux leaving the Sun, so Lyman-α solar irradiance is an important component to global spectral irradiance measurements and warrants special mention here. Profiles, shapes, and integrated intensities vary exceptionally widely from one structure to another (e.g. Gouttebroze *et al.* 1978; Lemaire *et al.* 1981; and Fontenla, Reichmann, & Tandberg-Hanssen 1988). The line shows strong variability on time scales of a few tens of seconds (Wilhelm *et al.* 1998).

While global emission models exist (e.g., Fontenla *et al.* 1999; Lean 1992), no simple proxy measurement has yet been found for Lyman-α emission. This has direct consequences for spacecraft orbit prediction. *Long-term AIS measurements of Lyman-α feature variability, combined with SIE irradiance observations, will enable the development of a correct proxy measurement based on the physics of measured features.*

The Lyman-α line profile gives a scan of emission from the high chromosphere down to the temperature minimum. The diagnostic power of the line is often ignored because of its optical thickness and its strong non-LTE formation conditions. With the development (Gouttebroze & Labrosse 2000) of non-LTE radiative transfer codes that can run on simple PCs, the very good statistics of Lyman-α make it an important diagnostic line for testing both wave and reconnective heating models of the chromosphere, and for testing the dynamics and structure of prominences.

Figure A2-12 shows the strong solar activity related variability in the Lyman-α profile. The core, formation altitude ~2100 km (Avrett 1996), varies by ~80%; while the peaks around the core, at 1300-1800 km, only vary by ~55%. *The high spatial and spectral resolution of the AIS full disk synoptic observations of Lyman-α will enable, for the first time, detailed development of physical models of the lower atmospheric radiance distribution of this important emission line.*
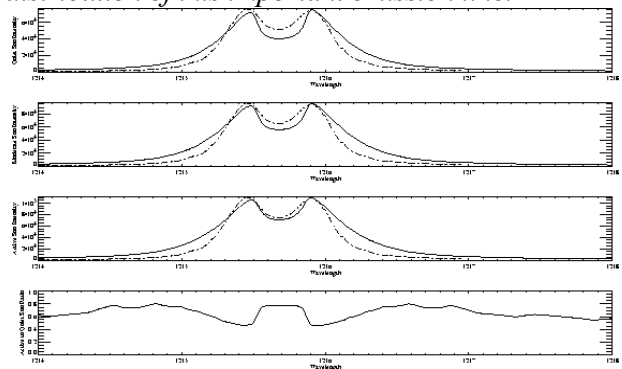
Figure A2-12: Profiles for Lyman-α compared to observations (Lemaire). The top three panels refer to the quiet, moderate and active levels and the lower panel shows the relative difference between the active and quiet sun computations, i.e. the expected variability across the profile. (from Fox *et al.* 2002)

A.2.6 Mechanisms of Small Scale Energy Release

[SDT Question 3; Campaign modes]

The injection of energy into the solar chromosphere and corona is determined by the magnetic field. The network "magnetic carpet" submerges and is replaced by new flux on timescales of 40-70 hours (Hagenaar *et al.* 1998; Lites *et al.* 1996), comparable to the supergranulation timescale, and on smaller scales flux concentrations also evolve, emerge, and disperse in association with the granulation and its evolution time of just 5-10 minutes (Lin & Rimmele 1999). Both of these processes inject

energy into small, impulsive heating events that are thought to be directly caused by magnetic reconnection. While the recycled small-scale field embodies enough energy to heat the corona, it is not clear whether enough *free* energy is dissipated by reconnection, and the answer depends on the detailed physics of reconnection. AIA will have difficulty probing the low temperature plasma in the energetically important transition region and chromosphere, and cannot capture the spectral signatures required. *AIS observations are critical to understanding the energetic effects of small-scale reconnection.*

Limitations of EUV imaging. EUV imaging instruments can identify brightening and heating events but cannot distinguish between wave driven and reconnective small-scale heating. Small, rapid brightness variations in coronal filamentary structure have been used as examples of small scale reconnection heating the corona (e.g., DeForest *et al.* 1997; Title *et al.* 2000). But recently, Shibata (2002) has demonstrated that low frequency, 1 km/sec amplitude Alfvén waves launched from the photosphere rapidly form nonlinear, turbulent shocks that grow to 10 km/s, develop nonlinear instabilities, and deposit their energy into turbulent shocks in only a few Mm. This process produces a stochastic heating signature that mimics the heating and EUV brightening patterns normally associated with small-scale reconnection. Spectral measurements are required to distinguish the two phenomena.

An example of the importance of time/space resolved Doppler measurements is the "explosive event" observations by Innes *et al.* (1997) with *SOHO/*SUMER. They clearly show rapid two-jet acceleration by small-scale reconnection (Figure A2-13). Several important points are clearly illustrated. (i) The position of the brightest emission does not move although Doppler-shifts over 100 km/s persist for at least 4 min. (ii) The beginning of the event is marked by large Doppler-shifts, not an intensity increase. (iii) The plasma is flowing away from the site of brightest emission. Each of these points are essential for understanding the energy flow in the structure and none could be obtained from images.

Combined EUV Imaging and Spectroscopy. Three examples demonstrate the synergy between sampled spectroscopy and high resolution imaging. First, without images, rapidly varying, spectrally observed small-scale flows cannot be related to the
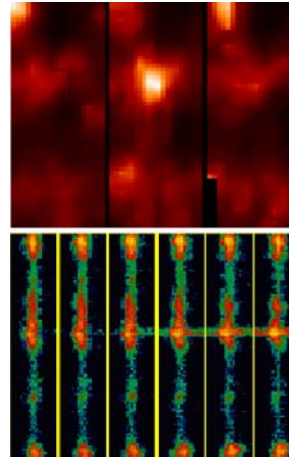
Figure A2-13. Blinkers and explosive events seen with different instruments. TOP: Blinker imaged with CDS. Images taken 10 minutes apart; pixels are 2". BOTTOM: Explosive event onset seen with SUMER. Images taken 10 seconds apart. Spatial scale is similar to CDS scale at top.

larger-scale atmospheric dynamics. In particular, emissions from different temperatures are often spatially offset although they are related. Chae *et al.* (1998) found H-α upflows with velocities of 15-30 km/s within 5" of UV high Doppler-shift events, but were unable to obtain information on the timing and causal flow of the events. The upflows are clearly coming from lower in the atmosphere than the UV microflares and therefore for models of the energy input sites it is critical whether they are seen before or after the UV events; well-synchronized imaging and spectral measurements are critical.

Secondly, in UV flashes seen by TRACE, the brightest emission comes from the sites of high pre-event plasma density, not the sites of highest energy input. Benz & Krucker (1999) proposed that a primary energy source of UV brightenings is reconnection in the corona generating high energy particles that then heat and accelerate the chromospheric plasma below. Recently, Tarbell *et al.* (2000) argues that the photosphere is the primary energy input site and that reconnection here produces many shocks that interact and generate observed flows in the transition region. However, imaging alone cannot distinguish between these models of energy release, because they are distinguished primarily by different relationships between enhanced EUV emission, motion, and spectral line broadening in the plasma. *Together, AIS and AIA have the combined temperature coverage, spectral resolution, spatial resolution, FOV, and time cadence to significantly advance understanding of energy transport and release associated with small scale reconnection.*

Finally, SOHO/CDS sees transient brightenings in the transition region called "blinkers" (Harrison 1997), with no observed

velocity change or coronal component. Existing instruments cannot resolve whether these "blinkers" and explosive events (Figure A2-13) are related. *By providing, for the first time, time/space resolved EUV/FUV spectra that are stably coordinated and co-aligned with high resolution EUV imagers, AIA and AIS together will determine the relationship between explosive events, blinkers, and the menagerie of small reconnection-related events observed by SOHO.*

A.2.7 Spectral Plasma Diagnostics

The goal of AIS is to provide quantitative plasma diagnostics, to evaluate the temperature distribution along the line of sight, to estimate the mean electron density, and to measure the velocity, both transverse and along the LOS. AIS will also directly measure both low and high FIP abundances in many elements, allowing, for example, the characteristics of the solar wind to be traced back to their source regions on the Sun. These quantities are the basic ingredients needed to constrain the set of magneto-hydrodynamic equations that describe the physical model of the source. *Therefore, the tools provided by AIS are essential for an in-depth understanding of physical processes taking place in the solar outer atmosphere and at the root of the space weather phenomena.*

Elemental Abundances. Many element abundances may be monitored to investigate how elemental fractionation (the FIP effect) changes in different structures on the solar disk.

Density Diagnostics. Line ratios from Si III, O IV, O V, N III and N IV can be used to determine the electron density changes in the transition region (at around 10^5K) between the cell center, network and small-scale transient events.

Emission Measure Maps. Knowledge of the emission measure as a function of density and temperature allows the observer to construct new atmospheric models (and test existing ones). *AIS will provide emission measure maps for our fixed line list automatically, as level-2 summary data products during normal modes of operation.*

Forward Modeling. Atomic databases such as CHIANTI (Young *et al.* 1998) are now sufficiently accurate and complete to allow forward modeling to be performed. Particular features where the geometry is simple (e.g. loops) can be studied in great detail by folding the atomic data with 3-D models of N_e,T_e as a function of time, to be compared to the spectral observations.

Other aspects of forward modeling involve developing predictive models to describe particular structures or class of phenomena on the Sun, and then comparing simulated spectra with observations. Such modeling is particularly useful in highly dynamic, time-dependent situations where it is dangerous to apply traditional emission-measure analysis. *The AIS team will provide community support for forward modeling techniques, to be led by Science Working Groups and their Co-Chairs.*

A.2.8 Measurement Approach

AIS produces specific, quantitative, accessible plasma diagnostics: measurements of plasma density and flow, temperature structure, spatially resolved spectral radiance, and elemental abundance. This is accomplished through innovative instrument design (§A.3.1), uniform, synoptic observing modes (§B.1), and automated generation of relevant data products (§B.2). Dual-slit spectral windowing (below and §A.3.1.2) doubles the effective collecting area of the instrument. "Echelle-mode" rastering (§B.1) of the slit yields sampled high spatial resolution spectra while boosting time resolution by more than a factor of ten. *AIS placement on SDO enables synoptic spectral imaging science that can be accomplished in no other way.*

AIS Wavelength Range. The AIS wavelength range provides; 1) *complete* temperature/height coverage of the solar atmosphere (§A.2.1, Figure FO1-2); 2) significant overlap with SIE and AIA, including the important HI Ly-α 1216 Å line (§A.2.3, A.2.5); and 3) overlapping 1st order lines above the Lyman edge to couple observations with HMI and provide chomospheric lines for wavelength velocity reference (Hassler *et al.* 1991a,b).

Instrument Requirements. AIS spectral resolution is set by the need to determine bulk motion to the ±2 - 5 km/sec level. With 0.2-pixel centroiding, AIS achieves ~±3 km. Spatial resolution matches AIA. The field of view is set by the need to image the largest possible field while maintaining high spatial resolution, in order to observe simultaneously small scale events and their effects on large scale structures such as two or more active regions.

Observational Requirements. The nominal AIS exposure time is one second, balancing the needs for high time resolution and photon statistics. Large-scale average count rates are shown in Table

FO1-3. One-second exposures allow full resolution spectral fits in the quiet Sun network, plage, prominences, active regions, and flares, throughout the AIS temperature range.

The normal AIS observing mode produces "Echelle-mode" raster scans with 15" spacing between slit positions, to encompass over 30% of the solar disk in 36 seconds, matching observed time scales of small network brightenings, coronal filamentary structure, spicules, and MHD wave trains observed throughout the solar atmosphere. The 15" spacing matches the observed width of the chromospheric network and provides several samples across prominences and active regions.

Dual Slit Spectral Windowing. The AIS standard observing mode and synoptic full-disk scan both use two parallel 16' long slits spaced 15" apart, effectively doubling the instrument's collecting area while not affecting velocity or line width diagnostics in the standard line set. The dual slit doubles the scan frequency and also provides a unique opportunity to distinguish motions perpendicular to the slit direction. *By observing the transverse component of plasma motion across the slits and LOS component of the motion spectrally as a Doppler shift, we are able to determine the 3-D velocity vector of the moving plasma.*

The inter-slit spacing and grating dispersion are matched to prevent blending of the lines in Table FO1-3, even in the presence of Doppler shifts up to ±400-600 km/s. This upper limit requirement on the maximum resolvable Doppler shift was based on the distribution of likely prominence speeds and estimates of the LOS component of transverse flows coming out of sunspots (Title 2002). Detailed modeling and further design optimization will occur during Phase A. Figure A2-14 shows a simulated spectrum for a

Figure A2-14: Sample AIS spectral window from Detector C showing the simulated spectrum from a traditional single slit, and AIS dual slit with 15" used for Standard Mode observing rasters. Spectral windows will be cataloged according to emission line and slit number (i.e. C IV 1548-1 or Ne VIII 770-2).

portion of Detector C. The 15" slit spacing corresponds to 23 pixels (1.56 Å) offset in the spectral dimension over all three detectors. There are no significant blends for any of the 20 standard lines listed in Table FO1-3.

A.3 Science Implementation

AIS science is made possible by a combination of innovative instrument features and operational techniques, and by our experienced, international team. Operations are discussed in §B. Here, we discuss the instrumentation and team that carry out the goals above.

A.3.1 Instrumentation

AIS is a high resolution, large FOV, rapid scanning Gregorian telescope and spectrograph with 3 ICCD detectors and a slit jaw camera. The spectrograph itself is 10x faster than the previous generation (exemplified by SOHO/SUMER, while maintaining high (1.2") optical resolution and good spectral (3 km/sec centroiding capability) resolution over an exceptionally wide field of view. Pointing and rapid scanning are achieved with a 6-axis hexapod actuator that steers the primary mirror and is specifically designed for long duration, high frequency, repetitive scanning motions. An innovative dual-slit design doubles the scan rate of the instrument and permits 3-D vector velocity determination.

Each aspect of the AIS design has extensive heritage based on successful aspects of SOHO/SUMER, SOHO/CDS, *Rosetta/Alice,* Solar-B/EIS, STEREO/SECCHI, HST/COS, HST/STIS, TRACE, SAGE III and the sounding rocket programs of our science team.

A.3.1.1 Spectrograph Design Overview

The AIS optical design is summarized in Tables A1-1 and FO2-1 and diagrammed in Figure FO2-1. It incorporates an off-axis Gregorian telescope with a 12.5 x 31 cm^2 rectangular primary mirror and an effective focal length (EFL) of 430 cm. A 4'x16' field stop is located at the focus of the primary, and limits the flux on the secondary mirror to <10% that of the full solar disk (or ~2 W). The telescope focuses light onto the spectrograph entrance slit, then to an easily manufactured SVLS diffraction grating that optimizes both spectral and spatial resolution along the entire length of our 16' entrance slit. The Airy disk diameter at the slit plane is <0.6" at 1600 Å; comatic aberrations are <0.7" (FWHM) throughout the entire 16' FOV. The SVLS grating design
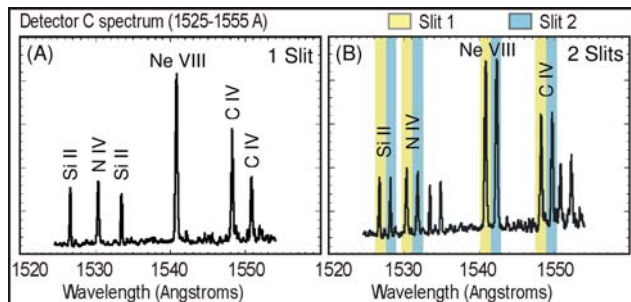
provides two tightly focused stigmatic imaging points at 1090 and 1560 Å (545 and 780 Å in 2nd order), with minimal spot size growth at all other AIS wavelengths (Figure A3-1). The grating spacing between the slit and focal plane provides a magnification of 1.26, resulting in an AIS EFL of 542 cm. Three intensified CCDs make up the spectrograph focal plane; an FUV-sensitive slit jaw camera (SJC) images a 4' x 16' region of the Sun at the slit plane.
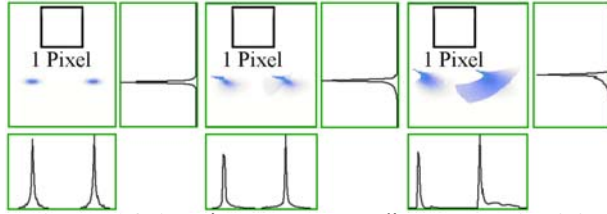

Figure A3-1. Point source spot diagrams at 1550.0 and 1550.1 Å. Left-to-right: on-axis, 4', and 6' off-axis. Below and to the right of each spot diagram shows a spectral and spatial amplitude plot, respectively, across the spots.

The optics and detector subsystems are housed in a highly-baffled graphite-epoxy structure to minimize thermal gradients. The AIS design incorporates two mechanisms that operate routinely, and two door mechanisms that open once on orbit (§A.3.1.5.2). All mechanisms have significant flight heritage. A dedicated AIS Data Processing Unit (DPU) controls all instrument functions and handles all science and housekeeping data as well as instrument telecommands to and from the spacecraft (S/C).

Our standard observing sequence includes 1-s exposures with all four CCDs, followed by frame transfer and readout to the DPU. During the frame transfer period (0.2 s), the primary mirror is stepped to the next position in the raster (typically a 30" step), and the next 1-s exposure takes place while the exposure is read out to the DPU (<1 s). This sequence is typically repeated 30 times in 36 s to complete a raster scan (see §B for mission operations details).

Optical System Design. *The Gregorian telescope design was chosen over a single-element design because of its much lower off-axis aberrations at the entrance slit (~15x less) which is dominated by coma in a single mirror telescope design. This optical design is also superior in spectral and spatial resolution performance (by factors >5 at large off-axis angles) to a single parabolic mirror feeding a Rowland-circle*

spectrograph or Wadsworth design, due to (i) the Gregorian's inherent low comatic aberration performance across the wide 16 arcmin FOV; and (ii) the low subtended angle between the incident and diffracted rays achievable with the SVLS grating. Moreover, only with near unity magnification can a single element spectrograph cover the entire wavelength range necessary to sample the complete solar atmosphere.

A.3.1.2 Optical Design/Performance

The AIS optical component specifications are summarized in Table FO2-1. Zeiss will build the telescope optics, and Jobin-Yvon (JY) will fabricate the SVLS grating. Both have years of experience in space flight optics. The telescope mirrors and grating use boron carbide multilayer coatings ($Al/MgF_2/B_4C$). These coatings have demonstrated higher reflectance than single layers of SiC or B_4C in the spectral region from 500 Å to 1216 Å, and reflectance comparable to SiC at wavelengths >1216 Å (Larruquert & Keski-Kuha 1999). Boron carbide also enhances the short wavelength portion of the passband to optimize observations of the important Si XII line at 521 Å.

Ray traced point-spread functions for AIS are shown in Figure A3-1. We will easily centroid line profiles to within 1/5th of a pixel providing velocity resolution of 2-4 km/s across the full AIS wavelength passband and FOV.

A zero-order light trap is located along the wall adjacent to the grating, and a small Kr flat field lamp (1236 Å) provides illumination of the three main detectors (A, B, and C).

Entrance Slit Design. The slit assembly contains the slit substrate and the selection mechanism. The slit substrate is highly polished stainless steel coated with Al/MgF_2 for enhanced FUV reflectivity for the SJC. The slit substrate provides four separate slit apertures. Slit 1 is a single 1" x 16' (0.021 x 20 mm^2) entrance slit. Slit 2 is a pair of parallel 1" x 16' entrance slits spaced 15" apart. Slits 1 and 2 are the primary AIS entrance slits used for the standard synoptic observations. Slits 3 and 4 are calibration slits. Slit 3 is a single 1" x 16' entrance slit with a LiF window that rejects 2nd order wavelengths and allows sorting of first and second order wavelengths. Slit 4 is a rectangular aperture (FOV 4" x 16') for in-flight calibration with stellar targets and pseudo-flatfielding.

Instrument Sensitivity. The three AIS focal plane detectors are ICCDs coated with KBr and

CsI photocathodes on the A/B, and C detectors, respectively. A ±2 Å region around H Ly-α on Detector B will be left bare and includes a 10% transmission mesh to reduce the count rate of this bright emission. The predicted AIS effective area (Figure A3-2), was computed using published reflectivity values for the boron carbide multilayer coating (Larruquert & Keski-Kuha 1999); a grating efficiency based on past measured results with similar holographic, ion-etched gratings in the SUMER instrument; and photocathode quantum efficiencies (QE) published by Siegmund *et al.* (1987) for KBr and CsI. AIS count rates estimates are listed in Table FO1-3.
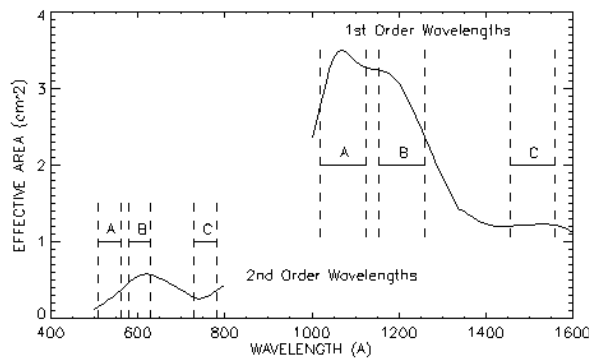
Figure A3-2. AIS effective area for 1st and 2nd order wavelengths. The passband region of each detector (A, B, and C) is also shown. Detectors A and B use KBr photocathodes; Detector C is CsI coated.

A.3.1.3 Detector/Focal Plane Design

AIS uses three ICCDs at the spectrograph focal plane, and one backside-thinned CCD for the SJC. The three ICCDs utilize two separate MCP intensifier stages: one for Detectors A and B, and one for Detector C (Figure FO2-3). Rutherford Appleton Laboratory (RAL) and Mullard Space Science Laboratory (MSSL) are responsible for the design, fabrication, and component testing of the CCDs and associated electronics. UC Berkeley (UCB) is responsible for the design, fabrication, and testing of the intensifier stages; the detector vacuum housing and door mechanism; integration of the CCDs to the intensifier; and final component level testing of the completed ICCDs before delivery to SwRI.

Intensifiers. Detectors A and B share a single 68 x 30 mm^2 MCP intensifier stage that feeds two CCDs, separated by an 8 mm gap. Detector C utilizes a 30 mm^2 MCP intensifier stage. Both MCP photocathodes are solar blind (visible light sensitivity of <10^{-13}).

A spectral resolution element of 68 mÅ (1st order) requires an ICCD resolution goal of >29 line-pairs/mm (lp/mm) (34 μm per lp, or 17 μm per resolution element). UCB has achieved better than 50 lp/mm, without Moire effects, and an MTF of >35% at 32 lp/mm (Figure A3-3; Vallerga 1996). They have built similar ICCD configurations that have worked well for SOHO/CDS, IMAGE/WIC, and SERTS (GSFC), TXI (SAO) sounding rocket experiments.

Figure A3-3. Air Force Test pattern image for a 6 μm pore MCP-ICCD with resolution of 51 1p/mm.
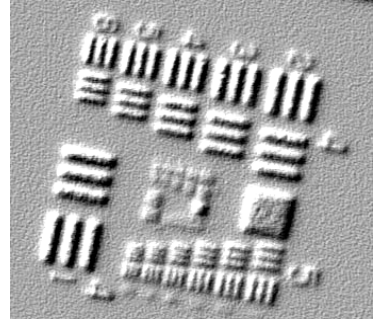
The AIS ICCD detectors have two significant design advantages over direct readout MCP detectors such as the crossed delay-line (XDL) detectors used in the SOHO/SUMER instrument: a) higher dynamic range; and b) longer detector lifetime. Both of these advantages stem from the ICCD's ability to operate with low, adjustable MCP output gains between 10^3-10^5 electrons pulse^{-1} (by varying the applied high voltage level to the MCP), whereas the XDL detector requires a fixed MCP output gain of >10^7 electrons/pulse.

The ICCDs can operate at gain values as low as ~10^3; this allows for a count rate capability that is 10^4 higher than SUMER. The ICCDs can sustain count rates >10^5 counts pixel^{-1} s^{-1} (~10^{11} counts s^{-1} over the entire array). During observations of faint signals, the ICCDs can operate at full gain (~10^5) in photon counting mode that matches both the sensitivity and the low noise level (~0.25 events s^{-1} cm^{-2}) of SUMER. An autoranging technique similar to that used by TRACE will adjust the MCP voltage (and thus MCP gain) based on the CCD output distribution per exposure. ICCD stability and calibration are ensured by a pre-integration scrub, preflight cleanliness (§A.3.1.10), and periodic in-flight flatfielding.

CCDs/Electronics. The baselined CCD is the existing backside-thinned Marconi CCD42-80 frame transfer CCD with 2048 x 4096 pixels, (2048 x 2048 active pixels) that will operate in non-inverted mode to ensure good full well capacity (100k-150k e$^-$). The CCDs will be

procured and tested by MSSL prior to integration with the intensifiers and housing at UCB. Each CCD will be cooled to -70ºC with passive cooling to radiators to achieve a low dark noise of ~0.1 electron s^{-1} pixel^{-1}. These devices have two parallel 2 Mpixels s^{-1} output amplifiers (14-bits/pixel) with an rms readout noise of <12 e$^−$ pixel^{-1}. The ICCD will be electronically shuttered during the 0.2 sec frame transfer period, by lowering the MCP voltage 20-25%. The vacuum housing surrounding the ICCDs will provide an equivalent 15 mm Al shielding to minimize radiation exposure to <6 krad over the mission life with a radiation dose margin (RDM) of two (Wertz and Larson 1999).

The CCD control and readout electronics is based on the lightweight, low-power CCD electronics design developed by RAL for STEREO. Controlling all four AIS CCDs from a single camera controller box minimizes overall size, mass, and power. To minimize power, the output MUX of each CCD is operated at reduced clock voltage. These electronics are composed of parts with >50 krad radiation tolerance.

ICCD Vacuum Housing. An ICCD vacuum housing similar to that used on *Rosetta/Alice* minimizes contamination exposure and maintains the effects of the UV scrub on the MCPs, ensuring radiometric stability. This housing allows the ICCDs to remain under vacuum at all times during integration, test, handling, and transport both at the AIS instrument level and when AIS is integrated to the S/C. The detector door at the entrance to the housing will include an MgF$_2$ window that will allow FUV wavelengths >1200 Å to reach the detector in the unlikely event of a door failure.

A.3.1.4 Slit-Jaw Camera (SJC)

To co-align the AIS spectrograph with the AIA and the other SDO instruments, and to provide low chromospheric images in the 1500-1700 Å region, an FUV-sensitive backside-thinned CCD camera images the front surface of the entrance slit plane. The slit plane is tilted 2º-3º to reflect incident light onto a pair of flat relay mirrors that fold the light to a light-tight box containing a UV-transmissive MgF$_2$ lens, a broadband (200 Å wide) interference filter centered at 1600 Å, a visible light blocking filter, and the CCD camera (Figure FO2-1). The MgF$_2$ lens re-images the 4' x 16' region of the slit plane onto the CCD with 1:1 magnification for an image plate scale of 0.65" per pixel. The CCD is the same Marconi 4280 frame transfer CCD used in the spectrograph focal plane. The light path from

the first relay mirror to the CCD is enclosed in a baffled tube structure that prevents scattering back into the spectrograph. The SJC wavelength matches the SJC LMSAL/AIA 1600 Å channel; and will be finalized during Phase A.

A.3.1.5 Mechanical/Thermal Design
A.3.1.5.1 Structure

The AIS instrument is packaged in a rigid, low CTE graphite epoxy structure built by COI, with direct flight heritage from SOHO/UVCS. The optical bench uses an orthogrid core with top and bottom face sheets, all of the same composite material and Titanium attachments at all optical element hardpoints. Thermal expansion of the complete optical assembly is ~0.1 ppm/°C, in all directions. Thermal stability of the structure minimizes the need for active refocusing of the optics. The first vibrational mode of the preliminary structural analysis is 50 Hz.

A.3.1.5.2 Mechanisms

The AIS design includes: 1) a front aperture door based on the SOHO/LASCO and SUMER aperture door design; 2) an ICCD housing vacuum door; 3) a slit changer mechanism; and 4) a combined Hexapod motion actuator and piezoelectric transducer (PZT) image stabilization system (ISS) stage attached to the telescope's primary mirror. The ISS is necessary for AIS to meet its spatial and temporal resolution performance objectives. Each mechanism has extensive design and/or flight heritage.

Front Aperture Door. The AIS aperture door has direct flight heritage from SOHO/SUMER and LASCO. The door mechanism consists of a stepper motor driven lead screw located inside the door hinge, allowing rotation of the door by 270º and can be stalled at any desired angle. The door is not vacuum tight, but a labyrinth seal around the rim allows a small overpressure inside the instrument with purge gas supplied to the interior volume. A redundant opening device based on a wax actuator can also open the door.

ICCD Housing Door. The ICCD housing door is similar to both the HST/COS and the *Rosetta/Alice* detector doors (Figure A3-4). The door can be opened and closed via telecommand. It utilizes a vacuum gate-valve style design that is flight qualified for HST/COS.

Slit Changer. The AIS slit changer has direct flight heritage from SOHO/SUMER. It consists of a holder for the slit substrate moving on twin
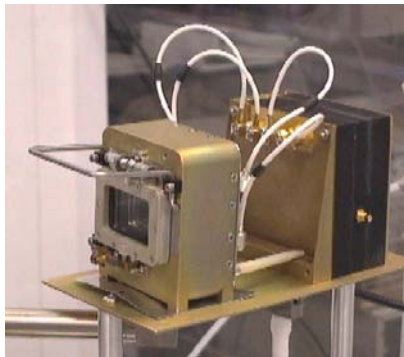
Figure A3-4. *Rosetta/Alice* detector vacuum housing and door assembly.

parallel linear ball bearings, driven by a stepper motor and a ball lead screw.

Image Stabilization, FOV Scanning, and Focus System. The Gregorian telescope primary mirror is mounted to a combined Hexapod actuator and high bandwidth tip/tilt PZT system. The PZT system was developed by Alenia Spazio, and has direct heritage from the SAGE III ISS experiment. The Hexapod system consists of six electro-mechanical linear actuators arranged as three trapezia between upper and lower platforms (Figure A3-5). It rotates the primary mirror about its focus allowing FOV scanning across the slit plane with no increase in off-axis optical aberrations. The Hexapod has an angular scan motion of ± 2300" in both axes at a maximum scan

rate of 1'/s. Repeatability is <1". This mechanism also provides focus control with a full translation range of ± 3 mm and a step size of 1 µm. To protect the mechanism for launch loads, the linear actuators are unloaded during launch using a latched off-loading device. Redundant wax-pellet actuators release the latch once the S/C is in orbit. The PZTs provide

Figure A3-5. The Hexapod/PZT tip/tilt actuator.

active jitter control with feedback from the S/C Guide Telescope. The PZTs provide rapid tip/tilt motion in a 10" range with an angular resolution of 0.1" (rms) at 25 Hz.

An optical encoder monitors mirror displacements with high accuracy, providing error signals to the Mirror Control Electronics (MCE) that will control and drive both the Hexapod and PZT systems. Pointing data from the S/C Guide Telescope will also be input to the MCE that will compute the error signals for the PZT stage for

jitter control. The MCE and associated software are built by Alenia Spazio.

A.3.1.5.3 Thermal Design

The geosynchronous orbit is thermally stable most of the year. The AIS payload is thermally isolated from the spacecraft bus to simplify thermal design and minimize spacecraft-payload thermal interactions. Active thermal control via heaters controlled by the DPU maintains constant temperature throughout the AIS structure to maintain optical performance. Under nominal conditions, 7 W of operational heater power will be required to maintain temperature. During eclipse periods, AIS will need an additional 10 W of survival heater power. Survival heater control is maintained by the S/C with mechanical thermostats and survival temperature monitors.

Passive radiator panels remove heat from seven key locations: the primary and secondary mirrors, the field stop light trap, and the four CCD cameras. The instrument electronics enclosure is thermally isolated from the spectrograph and is designed such that it can either use conductive cooling or radiate its internal heat directly to space (decided in Phase A). All CCD focal planes are thermally isolated from their respective electronics. Preliminary thermal modeling shows the CCDs at approximately −70°C using 700 cm^2 radiators. The primary telescope operates at ~90°C with a solar input power of 51 W. The telescope's primary mirror assembly utilizes a non-contacting heat removal plate directly behind the optical substrate. The field stop (FS) at the primary mirror focus is a highly polished Al/SiO-coated 4'x16' rectangular aperture (reflectivity >80% at IR and visible wavelengths). The FS surface reflects ~19 W of the remaining solar flux outside this FOV to a light trap between the telescope and spectrograph. The FS limits the power on the secondary mirror to 2.4 W, and 1.2 W at the entrance slit. The secondary mirror and the rest of the instrument are maintained at ~20°C.

A.3.1.6 Electronics

A block diagram of the DPU electronics is shown in Figure FO2-4. High rate science data from the DPU is sent directly to the spacecraft via an LVDS interface. Spacecraft commands and housekeeping telemetry are transferred via a MIL-STD-1553B interface. The DPU receives +28 VDC from the spacecraft, conditions it and distributes it to the appropriate instrument entities.

Data Processing Unit. The DPU is an aluminum extended 6U cPCI chassis with walls that provide a minimum of 200 mils of shielding for operation in a geosynchronous orbit radiation environment. The DPU chassis houses all electronic modules, with designs based on those developed for the SwRI Deep Impact and Gamma-Ray Burst Monitor (GBM) projects.

Central Processor Module. The CPM is a 6U-cPCI bus master based on the Temic TSC695F SPARC processor. The module includes a MIL-STD-1553B interface, dual UARTs, EEPROM, PROM and SRAM, and local oscillators. In the high-speed mode, the CPM provides 20 MIP and 5 MFLOP performance which is more than adequate for the needs of the AIS instrument.

Camera Interface Module. The CIM utilizes the Atmel TSC901 IEEE 1355 controller along with LVDS receivers and transmitters from UTMC to provide a reliable high-speed interface between the four sets of CCD focal plane electronics and the DPU. The CIM science data formatter performs a hard-coded lossless data compression algorithm (based on a combination of RICE and square-root binning) on each of the four CCD focal plane data sets and then creates CCSDS compliant source packets which are forwarded to the spacecraft via an LVDS interface.

The CIM also provides the interface to the Hexapod/ISS, and handles input signals from the SDO Guide Telescope. The Guide Telescope provides the pointing data to the CPM via the cPCI backplane. The CPM combines the jitter data with mirror scan data and outputs corrections to the Mirror-Control Electronics (MCE).

General Purpose I/O Module. The GPIOM controls the aperture door, ICCD vacuum door, ICCD HVPSs, slit changer mechanism, flat field lamp, camera power, temperature telemetry collection, and heaters. Most functions provided by the GPIOM are discrete voltage inputs and outputs. The CPM, in combination with the GPIOM, provides complete closed loop active heater control of 16 heaters located around the instrument. Housekeeping data are transferred to the CPM for downlink.

High Voltage Power Supply. Two SwRI-built HVPSs drive the MCP intensifiers from outside the DPU chassis close to the focal plane. The supplies are programmable with an output up to -1500 V for the MCP stack, and -5000 V for the MCP-to-Phosphor gap. These HVPSs have flown on a number of space flight missions including IMAGE/MENA, *CASSINI*/CAPS, DS-1/PEPE, and *Rosetta/Alice*.

A.3.1.7 *Radiation Environment/Mitigation*

The expected total integrated dose (TID) over the 5-year mission with 100-mil Al shielding is >125 Krad (no RDM). With 200-mil Al shielding and an RDM of 2, the mission TID is <20 Krad. All AIS components have a TID of >30 Krad.

All components selected for the AIS have an SEL LET >40 MeV-g/cm^2 and are thus immune to SEL in geospace. SEU immunity is accomplished either through inherent device technology, or internal triple voting redundancy logic.

A.3.1.8 *Redundancy*

AIS is a single-string instrument, with some redundancy in the most critical systems. The Hexapod/ISS is inherently redundant, with 6 degrees of freedom, allowing limited motion even if one or more actuators fail. The detector door has a MgF$_2$ window which transmits 1st order radiation in the unlikely event of door failure. The aperture door includes a redundant wax actuator opener. Failure in one of the CCD electronic channels results in the loss of only one of the three CCD detectors (A, B, or, C) while still retaining function in the remaining two.

A.3.1.9 *Flight Software*

The AIS flight software (FSW) will be implemented in the ANSI-C/C^{++}programming language, and will execute on the Real-Time Executive for Multiprocessor Systems (RTEMS) operating system kernel. SwRI has an existing software development laboratory containing a TSC695F SPARC evaluation board enabling software development to commence prior to the availability of engineering model DPU hardware.

AIS FSW functions include sending housekeeping data, receiving commands to and from the S/C, and control of all instrument mechanisms, CCDs, and heaters. Observing sequences can control image exposures, the HVPS, raster scan motion, data windowing, compression, and formatting for science downlink. The total expected processor utilization to conduct all AIS functions is expected to be <50%.

A.3.1.10 *Contamination Control*

Instruments on early solar physics missions, such as OSO-8 and SMM/UVSP, have suffered instrument degradation and reflectivity loss due to photopolymerizing contamination. However, with

adequate contamination control and cleanliness procedures, these concerns are mitigated, as evidenced by our team's experience with SOHO/SUMER (Schühle *et al.* 1993; 2000). *The AIS team will use the same cleanliness and contamination control procedures as successfully used with SOHO/SUMER.* Moreover, our optical design minimizes thermal load and UV flux on the secondary mirror with a 4'x16' field stop, reducing total UV fluence.

Preventative design measures implemented early in the design phase include selection of materials with low outgassing properties (<1% TML, <0.1% CVCM); isolation of optical cavities from organic materials (including the placement of all electronic boards and components outside all optical cavities); passive heating of the optics; a front aperture door; a detector vacuum door; and a GN_2 purge system to allow for a continuous purge of the optical cavity during all activities through launch. AIS component and instrument integration take place in cleanroom environments certified at Class 1000 or better (FED STD 209E). The AIS ICCD vacuum housing is maintained under vacuum at all times. As was successfully done with SOHO/SUMER, outgassing with the aperture door partially open will be performed as part of the commissioning activities. We will implement a contamination monitoring program during the fabrication, I&T, and S/C activities with witness samples placed inside the AIS housing.

A.3.1.11 Instrument Assembly and Test Flow

We will construct one complete flight model (FM), one structural-thermal model (STM), and a subset of critical spare flight components that can easily replace flight unit components if needed. In addition, beginning in Phase A, we will build prototype or engineering models (EMs) of components that require early testing, to verify performance. Table A3-1 summarizes all of the AIS H/W and S/W components (including GSE) and the number of prototype/EM, flight model, and spare components to be developed, as well as direct heritage of the subsystem.

The FM AIS instrument component, subsystem, and integrated assembly and test flow are shown in Figures A3-6 and A3-7. All deliverable subsystems, including electronics, mechanisms, detectors and optics, are functionally and environmentally tested before integration.

A.3.1.12 Calibration

AIS will be calibrated both at the unit level and system level prior to launch. The spectral reflectivities of the mirrors will be measured at MPAE using witness plates coated simultaneously with the mirrors. The grating will also be measured

Table A3-1. AIS Test Verification Matrix

SUBSYSTEM	Responsible Institution	PROTOTYPE TESTS	FM TESTS	Heritage	# of UNITS* PT	FM	Sp
Structure	SwRI, USA (Manufacturer: COI)	Structural Loads, CTE vs. Temp., TB**	Structural Loads, Resonant Freq, CTE vs. Temperature	SOHO/UVCS AXAF	1***	1	0
Telescope Optics: Pri & Sec Mirrors	MPAE, Germany (Manufacturer: Zeiss)	Surface figure, roughness Metrology, coating reflectivity	Surface figure, roughness Metrology, coating reflectivity	SOHO/SUMER	1	1	1
Grating	IAS, France (Manufacturer: JY)	Metrology, coating reflectivity Grating efficiency	Metrology, coating reflectivity Grating efficiency, light scatter	SOHO/SUMER ROSETTA/ALICE	1	1	1
SJC Filter/Optics	SwRI, USA	N/A	MTF, Filter trans, Mirror/Lens eff.	TRACE	0	1	1
Telescope Ass'y	U. Padua, Italy (Manufacturer: Alenia)	Optical alignment/stability PSF/MTF, Vib	Optical alignment/stability, stray light PSF/MTF, Vib, TVAC, scan/ jitter tests	SOHO/UVCS	1	1	0
Hexapod Mechanism	U.Padua/Alenia, Italy	Life Cycle Test, Vib	Scan/Focus Tests, Vib, TVAC	SAGE III	1	1	0
PZT Stage	U.Padua/Alenia, Italy	Life Cycle Test	Jitter Tests, Vib, TVAC	SAGE III, TRACE	1	1	0
CCD/Electronics	MSSL, UK RAL, UK	QE, Dark Noise, Read Noise PSF/MTF Performance	QE, Dark Noise, Read Noise PSF/MTF Performance	STEREO/SECCHI	1/1	4/1	1/1
CCD Intensifier Stage	UCB, USA	MCP Gain/Dark Noise, QE, PSF/MTF Dyn Range, Spatial Linearity, Flat Field	MCP Gain/Dark Noise, QE, PSF/MTF Dyn Range, Spatial Linearity, Flat Field	SOHO/CDS, TXI (SAO) IMAGE/WIC, SERTS	1	2	1
ICCD Housing/ Door Assembly	UCB, USA	Vacuum, Functional Tests Door Life Cycle Test	Vacuum integrity Door Functional Tests	HST/COS ROSETTA/ALICE	1	1	1
ICCD Assembly	UCB, USA	PSF/MTF, QE, Dyn Range, Vib, TVAC Spatial Linearity, Flat Field	PSF/MTF, QE, Dyn Range, Vib, TVAC Spatial Linearity, Flat Field	SOHO/CDS, TXI (SAO) IMAGE/WIC, SERTS	1	2	1
Slit Changer	MPAE, Germany	Functional Tests, Life Cycle Test	Functional Tests, Vib, TVAC	SOHO/SUMER	1	2	0
HVPSs	SwRI, USA	Functional Test, TVAC	Functional Test TVAC, Burn-in	ROSETTA/ALICE IMAGE/MENA	1	2	1
C&DH Electronics	SwRI, USA	Functional Tests, S/W Testbed	Func Tests, Burn-in, Vib, TVAC	Deep Impact, GBM	1	1	0
FF Lamp/Electronics	SwRI, USA	N/A	Flux Output/Stability, Vib, TVAC	HST/STIS	0	1	1
Front Aperture Door	MPAE, Germany	Life Cycle Test, Vib, TVAC	Functional Test, Vib, TVAC	SOHO/SUMER	1	1	1
Thermal Control Sys	SwRI, USA	CCD Radiator TVAC, TVAC/TB	TVAC/TB**	IMAGE	1	1	0
AIS Instrument (incl. FSW, MGSE, EGSE, & EGSE S/W)	SwRI, USA	N/A	Metrology, FFT Opt alignment/stability Radiometric Perf/Calibration EMI/EMC, Vib, Acoustic, TVAC/TB**	SOHO/SUMER/UVCS ROSETTA/ALICE IMAGE/MENA, EUVS ROSETTA/IES	0	1	0

* PT=Prototype (or Engineering Model), FM = Flight Model, Sp = Flight Spares
** TB = Thermal Balance Test
*** The EM Structure will become the STM after completion of EM component testing.
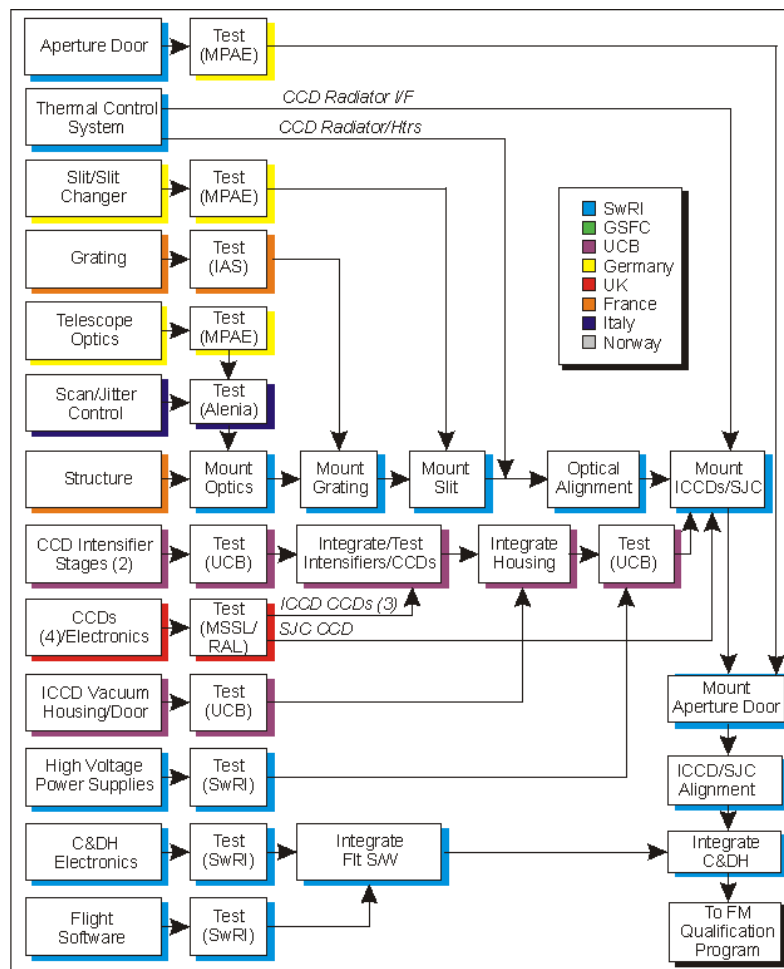
Figure A3-6. The AIS Subsystem assembly and test flow.

Figure A3-7. AIS Flight Model qualification test flow.
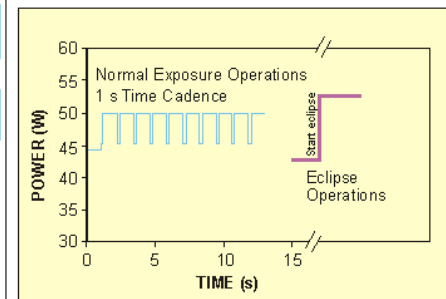
Figure A3-8. AIS power profile.

for diffraction efficiency across the AIS passband at IAS in Orsay, France. The reflectivity of the SJC optics will be measured at SwRI. The QEs of the ICCDs will be measured at UCB before delivery. MSSL will measure the QE of the SJC CCD before delivery.

System level radiometric calibration will be performed in SwRI's Vacuum Radiometric Calibration Facility. Using a collimated, tunable monochromatic UV standard-transfer light source calibrated at the BESSY storage ring in Berlin, we will measure the AIS effective area; characterize the spatial and spectral PSF; conduct wavelength calibration; and measure off-axis, out-of-band, and in-band stray light. On orbit, calibration is maintained by comparison with irradiance measurements from SIE and selected cross-calibration with AIA (e.g., SJC calibration).

A.3.1.13 Resource Requirements and Spacecraft Accommodations

The estimated mass, power, volume, and data rate resources required by AIS are shown in Tables FO2-1 and FO2-2. Figure A3-8 shows the predicted power vs. time profile during a typical observation sequence and during an orbital eclipse when science observations are suspended and additional heater power is required. All estimated AIS resources are within the AO guideline with healthy reserve.

Spacecraft Accommodation. The AIS is attached to the S/C by three kinematic flexures to eliminate optical bench distortions caused by thermal expansion and/or mounting surface irregularities. Figure FO2-5 shows the preferred mounting location of AIS on the S/C. The orientation of the spectrograph entrance slit (x-direction in Figure FO2-1) is parallel to the solar equator (along the East-West direction). The DPU electronics measures 20 x 15 x 12 cm^3, and is housed in a separate box that can be mounted separately on or inside the S/C.

Data Collection. Science data is acquired from each of the four 2048x2048 pixel focal planes of once per second and transferred to the DPU. Each frame produces 4 Mpixels of data and is digitized at 14 bits of resolution. The resulting 16

Mpixels of data are buffered and processed within the DPU. The DPU windows the data from each exposure (we baseline 50-pixel-wide swaths in each of 52 windows along the entire 16' slit width, plus the 4'x16' FOV of the SJC) and performs data compression (RICE and square root for a factor of ~3.75 compression) to create a data rate of 21 Mbps with 10% reserve.

Electrical and Mechanical Ground Support Equipment. The Electrical Ground Support Equipment (EGSE) will be used to facilitate the development, test, and calibration of the AIS instrument. It will provide protocol translation between the AIS Command and Telemetry Station (e.g. ITOS, ASIST, OASIS) and the instrument's 1553 interface, and accept science data packets via LVDS and forward them to the AIS Science Data Display and Analysis Station. Calibration and test use housekeeping software subsystems developed for flight, and *solarsoft* analysis software.

Mechanical ground support equipment (MGSE) will include a dedicated GN_2 purge regulator, a UV stim lamp and a vibration-isolated shipping container equipped to monitor humidity exposure, temperature, and shock levels.

A.3.1.14 Special Spacecraft Integration Requirements

AIS must be mounted to the S/C so that the long dimension of the slit is parallel to the solar equator. AIS must also have an unobstructed FOV of ±20º about the instrument boresight. We also request that AIS be optically boresighted to the other SDO optical instruments including AIA and the Guide Telescope. A set of optical alignment cubes will be mounted to the AIS housing to allow instrument alignment on the S/C.

During all phases of payload I&T on the S/C, AIS must i) be maintained in a cleanroom environment of class 10,000 or better (with the aperture door closed); and ii) have a continuous purge of clean, dry GN_2.

A.3.2 Science Team

The AIS Science Team has all of the required engineering and scientific expertise to successfully develop, test, integrate, operate, and scientifically exploit the AIS Science Investigation as well as fully support every aspect of the SDO mission development, operation and scientific activity. A major strength of the AIS project is the outstanding quality, breadth, and depth of the Science Team as

a representative cross section of the American and European solar physics communities.

Our team has been assembled and organized to enable and disseminate AIS data and modeling products to the larger ILWS community, while ensuring scientific closure through a systems approach to understanding the solar-terrestrial environment and its affects on life and society.

To coordinate these efforts, our Science Team is arranged into 6 Working Groups (WGs), with both a US and European Co-Chair for each. Table A3-2 lists the AIS Working Groups. The WGs are the backbone of our science team structure and organization. The WG Co-chairs are responsible for overseeing data analysis and modeling activities relevant to their specific SDO/AIS scientific objectives, organizing science team activities, disseminating relevant updates, and participating in GI selections related to their WG.

Relevant experience and specific roles of each team member is listed in Table A3-3.

Table A3-2 AIS Science Working Groups			
1) Reconnection, Waves and Shocks WG			
P. Judge (US Co-chair)		*M. Carlsson (European Co-chair)*	
T. Ayres	D. Longcope	D. Innes	K. Schrijver
K. Bocchialini	B. Fleck	M. Madjarska	A. Title
C. DeForest	K. Galsgaard	C. Parnell	M. Velli
G. Doyle	V. Hansteen	E. Priest	R. Walsh
2) Filaments, CMEs, ARs, and Flares WG			
K. Schrijver (US Co-chair)		*H. Mason (European Co-chair)*	
V. Andretta	L. Culhane	L. Fletcher	A. Poland
K. Bocchialini	B. DePontieu	R. Harrison	B. Thompson
P. Brekke	J. Gurman	T. Kucera	R. Walsh
	C. Kankelborg	M. Landini	A. Fludra
3) Solar Wind, Space Environment, Space Weather WG			
B. Thompson (US Co-chair)		*E. Marsch (European Co-chair)*	
G. DelZanna	R. Harrison	V. Pizzo	J.-C. Vial
S. Fineschi	D. McComas	G. Poletto	K. Wilhelm
		D. Spadaro	
4) Sources and Mechanisms of Irradiance Variability WG			
P. Fox (US Co-chair)		*J.-C. Vial (European Co-chair)*	
V. Andretta	P. Brekke	P. Lemaire	U. Schuehle
T. Ayres	P. Judge	D. Slater	K. Wilhelm
5) Data Products and Software WG			
C. DeForest (US Co-chair)		*V. Hansteen (European Co-chair)*	
M. Carlsson	J. Gurman	M. Landini	A. Poland
I. Dammasch	P. Judge	H. Mason	D. Spadaro
B. DePontieu	T. Kucera	S. McIntosh	B. Thompson
6) Calibration WG			
D. Slater (US Co-chair)		*L. Poletto (European Co-chair)*	
L. Culhane	P. Lemaire	M. Pelizzo	O. Siegmund
S. Fineschi	G. Naletto	U. Schuehle	P. Tondello
J. Lang	P. Nicolosi		N. Waltham

TABLE A3-3 AIS SCIENCE TEAM MEMBERS			
Individual	**Relevant Experience**	**Institution**	**Responsibility**
Principal Investigator			
Dr. Donald M. Hassler	SOHO/SUMER Co-I, SOHO/CDS/UVCS, PI/Co-I of seven sounding rocket flights, Spartan/UVCS, member SDO SDT	SwRI	Overall AIS investigation
US Co-Investigators (directly funded through this investigation)			
Dr. Tom Ayres	SOHO/SUMER, IUE, FUSE	CU/CASA	In-flight calibration development lead
Dr. Craig DeForest	SOHO/MDI, MSSTA rocket program	SwRI	MO&DA lead, Data Products WG chair
Dr. Peter Fox	RISE, SUNRISE Modeling Programs	HAO/NCAR	Sources of Irradiance Variability WG chair
Dr. Joe Gurman	SOHO US Proj. Sci., TRACE Mission Sci., SOHO/EIT, SMM/UVSP, SDAC Facility Sci.	GSFC	Database/archive design lead
Dr. Phil Judge	SUMER, CDS, ASP analysis	HAO/NCAR	Reconnection WG chair
Dr. Terry Kucera	SUMER science and data analysis	GSFC	Ground system development lead
Dr. Dave McComas	Ulysses, ACE, Cassini, Twins	SwRI	Instr. mgmt, connection to geospace
Dr. Art Poland	SMM/UVSP, SUMER, SOHO Proj. Sci.	GSFC	Solar modeling development lead
Dr. Karel Schrijver	SOHO, TRACE	LMSAL	Filament, CME, AR, and Flare WG chair
Dr. Oswald Siegmund	IMAGE, SOHO, Rosetta/Alice, GALEX	UC/Berkeley	ICCD Intensifier
Dr. Dave Slater	SOHO, Rosetta/Alice	SwRI	AIS Scientist, Calib. WG chair
Dr. Barbara Thompson	SOHO EIT, SDO Project scientist	GSFC	Space Weather WG chair
European Co-Investigators (not funded by NASA)			
Dr. Karine Bocchialini	SOHO/SUMER	IAS	ReconnectionWG
Dr. Paal Brekke	SOHO/SUMER/CDS	ESA	Irradiance Variability WG
Dr. Mats Carlsson	SOHO/SUMER	Univ. of Oslo	Reconnection WG chair, SW lead/Norway
Dr. Len Culhane	SMM/XMM, Yohkoh/BCS, Solar-B/EIS PI	MSSL	Coordination with Solar-B/EIS
Dr. Bernhard Fleck	SOHO ESA Project Scientist	ESA	European PC, ReconnectionWG
Dr. Richard Harrison	SMM/HXIS, SOHO/CDS PI	RAL	Hardware lead (UK)
Dr. Viggo Hansteen	SUMER, CDS Associate Scientist	Univ. of Oslo	Data Products WG chair, ReconnectionWG
Dr. Davina Innes	SUMER Co-I	MPAE	Reconnection WG
Dr. Massimo Landini	SOHO/UVCS, CHIANTI	Univ. of Firenze	Data Products WG
Dr. Jim Lang	Yohkoh/BCS, ADAS, SOHO/CDS	RAL	Calibration WG
Dr. Philippe Lemaire	SOHO/SUMER	IAS	Irradiance Variability WG, Calibration WG
Dr. Eckart Marsch	SUMER Co-I	MPAE	Solar Wind WG chair
Dr. Helen Mason	SMM, SOHO/SUMER/CDS, CHIANTI	Univ. Cambridge	Filament, CME, AR, & Flare WG Chair
Dr. Piergiorgio Nicolosi	SOHO/UVCS	Univ. of Padua	Calibration WG
Dr. Luca Poletto	SOHO/UVCS	Univ. of Padua	Calibration WG Chair
Dr. Eric Priest	SOHO	St. Andrews	Reconnection WG
Dr. Udo Schühle	SUMER Mission design/ops/calib.	MPAE	Hardware lead (Germany)
Dr. Pino Tondello	SOHO/UVCS	Univ. of Padua	Hardware lead (Italy)
Dr. Jean-Claude Vial	SOHO/SUMER, LYOT	IAS	Hardware lead (France), European Data Archive
Dr. Nick Waltham	Coriolis/SMEI, STEREO/ SECCHI	RAL	CCD camera design and development
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Dr. Charles Kankelborg	SOHO, MSSTA, MOSES rocket programs	MSU	Filaments, CMEs, AR, & Flare WG
Dr. Dana Longcope	MHD modeling, Solar-B Co-I	MSU	Reconnection WG.
Dr. Vic Pizzo	GOES, SXI	NOAA/SEC	Space Weather applications/data products
Dr. Alan Title	TRACE, SOHO/MDI	LMSAL	Coord. with LMSAL AIS/HMI team
European Associate Investigators (not funded by NASA)			
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Dr. Ingolf Dammasch	SUMER Associate Scientist	MPAE	Data Products WG
Dr. Guilio DelZanna	SOHO/CDS, CHIANTI	Univ. Cambridge	Space Weather WG
Dr. Gerry Doyle	SMM/UVSP/XRP, SOHO/SUMER/CDS	Armagh Obs.	ReconnectionWG, Data Products WG
Dr. Silvano Fineschi	SOHO/UVCS	Univ. of Torino	Space Weather WG
Dr. Lyndsay Fletcher	TRACE, SOHO/CDS, Yohkoh/SXT	Univ. Glasgow	Filaments, CMEs, AR, & Flare WG
Dr. Andrzej Fludra	SOHO/CDS	RAL	Filaments, CMEs, AR, & Flare WG
Dr. Klaus Galsgaard	SOHO/CDS	St. Andrews	Reconnection WG
Dr. Maria Madjarska	SOHO/SUMER/CDS	Armagh Obs.	Reconnection, Waves & Shocks WG
Dr. Scott McIntosh	SOHO/SUMER	ESA	Data Products WG
Dr. Giampiero Naletto	SOHO/UVCS	Univ. of Padua	Calibration WG
Dr. Clare Parnell	SOHO/CDS, TRACE	St. Andrews	Reconnection WG
Dr. Maria Pelizzo	SOHO/UVCS	Univ. of Padua	Calibration WG
Dr. Giannina Poletto	SOHO/SUMER/UVCS	Arcetri Obs.	SW, Solar Environment WG
Dr. Daniele Spadaro	SOHO/UVCS/SUMER/CDS	Obs. Catania	Data Products WG, Space Weather WG
Dr. Marco Velli	SOHO/UVCS	Univ. of Firenze	Reconnection WG
Dr. Robert Walsh	SOHO/CDS	Univ. Lancashire	Reconnection WG, AR, & Flare WG

B. Mission Operations and Data Analysis Plan

The AIS investigation is designed specifically for streamlined operations and uniform data product generation. After a 4-6 week commissioning phase at the SDO MOC, normal science operations are carried out from the AIS SOC located at SwRI's Boulder, Colorado facility. Compiled command loads are sent to the SDO MOC via the Internet. Data integrity and instrument health & safety are monitored from the SOC, reducing operations cost. The SOC is staffed 40 hours per week. The operations plan incorporates university student involvement in coding, data inspection, and health monitoring, leveraging operations and college-level outreach. Only occasional commanding is required and no need is anticipated for spacecraft support above the level described in the AO.

The standard AIS observing sequence is a repeating, broad-spectrum 16'x15' raster scan every 36 seconds with constant pointing for 3-9 months, interleaved with a synoptic program of four 20-minute full disk scans every day. This standard observing mode eliminates the need for daily or weekly planning, and runs without ground input for weeks to months at a stretch. The remaining 1-3 months per year are devoted to observing campaigns that run for 1-12 weeks, limiting complexity while exploiting the instrument's capabilities throughout the solar cycle. The synoptic program continues during campaigns, providing a full-disk spectroheliogram every six hours throughout the entire mission at a cost of just over 5% of the observing time. The observing strategy is described in §B.1

Quarterly planning teleconferences determine science priority and pointing guidelines for the following quarter. During campaign season, a weekly planning teleconference allows collaboration with other observatories and reaction to anticipated solar conditions. Each campaign season addresses specific goals chosen by the science team in the previous quarter; the PI has final authority. Each campaign is associated with a particular "campaign scientist" who coordinates joint observations. AIS observing mode and pointing are typically changed at most weekly during campaign season. It is not necessary for campaign scientists to travel to the SOC.
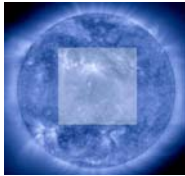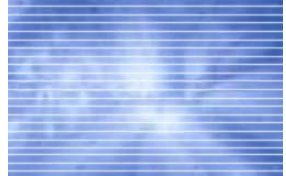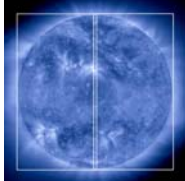
AIS data are organized into raster scans and reduced automatically on the ground to image data products, reducing cost and complexity of analysis. Data products are designed for interoperability with the rest of SDO and other observatories, and joint SDO studies are a major part of the analysis plan. The data pipeline, archiving system, and analysis plan are described in §B.2.

B.1 AIS Observing Strategy

Most AIS spectral scans are operated in "echelle mode": spectra are taken up to 15" apart, much farther than the 1.2" optical resolution. The high optical resolution yields precise spectral measurements of small structures; large scan steps permit high time resolution. The normal echelle scan provides "ground truth" about plasma composition, temperature, and motion every 36 seconds at key points across 30% of the solar disk; these measurements combine with AIA and HMI images to fulfill the SDO science goals.

Line selection is fixed for normal and most campaign observations (Table FO1-3) and was chosen for the broadest possible temperature coverage. All 26 windows are downlinked with every exposure. Exposure time is nominally 1 sec and ICCD gain is autoranged independently for each raster index position (§A.3.1.3). Inflight calibration is achieved for ICCD gain with ICCD

Table B1-1. Planned Standard Observing Mode for AIS		
Observation	Science goals addressed	FOV & slit spacing
Normal scan 16'x15' FOV, 15" spacing 2x30 slit pos. 36 sec/scan	CME & flare precursors; CME onset & accel.; AR evo.; loop dynamics & structure; wave studies; imp. heating; signatures & role of reconnection; filament stability.	
Synoptic scan Full disk FOV, 1.8" spacing 20 min. scan 4x/day	Spectral irradiance & radiance structure & variability; solar wind source & evolution; prominence stability; abundance variations; emission measure of solar features	[1.8" spacing]

voltage exposure sequences taken just after each synoptic scan, for absolute intensity using SIE data and full-disk AIS scans, and for wavelength via chromospheric lines. One-second exposures allow full spatial resolution spectral fits in network, plage, prominences, active regions, and bright structures in quiet Sun.

The spectrograph entrance slits are horizontal to eliminate the need for tracking of solar rotation. Individual 1" features remain in view for over 24 hours at all times and for over 48 hours more than half the year, without pointing adjustment. Large-scale features take 5-7 days to cross the FOV. Upper and lower slit exposures are used interchangeably in assembling scans. Scan modes denser than 15" use staggered pointing to achieve uniform sampling. Every exposure is accompanied by an SJC image that is used by the data pipeline software to verify co-alignment and pointing. The SJC passband is 1500-1700 Å to match the LMSAL AIA but could be adjusted in Phase A.

AIS pauses science observation during eclipses but continues observing >22 hours per day during eclipse seasons. Eclipse pauses may be triggered at commanded clock times or by a spacecraft flag; the design requires input from the SDO spacecraft team during Phase A.

B.1.1 AIS Standard Observing Mode

The standard AIS observing mode is described in Table B1-1. The 36-second cadence of the normal raster scan matches the observed time scales of small network brightenings, of filamentary structures in prominences, coronal loops, and plumes, of spicules, and of MHD and Alfvén wave trains observed throughout the atmosphere. The 15" spacing is chosen to match the observed width of the chromospheric network and provide several samples across prominences. The field of view can simultaneously cover both active latitudes over most of the solar cycle, recording spectral signatures of CME onset for nearly all Earth-directed CMEs.

The synoptic scan satisfies three science goals: (i) providing spatially resolved and spectrally complete input to full-disk irradiance and emission measure models; (ii) searching for spectral signatures of pre-eruptive conditions in prominences and active regions; and (iii) monitoring the evolution of the solar wind source structure and large-scale flows over the whole disk. The 6 hour cadence samples the time scale on which solar wind source regions are thought to

evolve, and is fast enough to track the effects of supergranular motion. The scan uses 19.5 minutes out of 20 allocated; the final 30 seconds are used to calibrate the ICCD voltage-gain relationship.

B.1.2 AIS Campaigns

Some SDO science goals require modified AIS observing programs that operate at higher cadence or density, or generate complete spectra rather than windowed lines. Special campaign observations use predefined sequences to fulfill these goals. Here we describe 4 campaigns that are required for particular SDO science objectives.

Fixed slits: 16'x15" FOV to observe the interplay of heating, flow, and density at 1-2 second cadence, equal to the coronal Alfvén crossing time of AIS pixels. The extremely high cadence records acceleration profile and subsequent thermalization of small reconnection-related jets, and tests for the postulated formation of ~0.1 Hz Alfvén shocks that may heat the transition region and lower corona (Shibata *et al*. 2002).

Rapid scan: 16'x2' FOV with 15" spacing on a 6 second cadence, to study AR loop formation and standing wave excitation, impulsive heating of the chromosphere and corona, and the role of chromospheric shocks.

Dense scan: 16'x2' FOV with 1.2" spacing at 60 second cadence, to determine spatial distribution, energetics, and energy partitioning of small scale reconnection, shock formation, and heating.

Single slit: Full-sun FOV with full detector readout, dense scan, and single slit. Creates complete, unblended spectra for high S/N, calibration, and detailed spectral studies.

B.2 Data Reduction, Analysis and Archiving

The AIS data plan will mature during phase A under guidance from the SDO SWG. Here, we present a sample plan that satisfies AIS science requirements and fits within mission resource constraints.

AIS has an open data policy. All data, derived data products, and calibration and analysis software are made available to anyone who requests them as soon as is practical. Level 1 and summary data may prove useful to space weather predictors and are available, on a best-effort basis, within 15 minutes of receipt of the corresponding telemetry at the AIS SOC. Analysis software and calibration information are distributed via *Solarsoft*

and the World Wide Web on the same terms as the science data themselves. Because multi-instrument observations are vital to SDO and to AIS, we will explore solutions such as the Virtual Solar Observatory (Hill 2001) that cross-link data from multiple observatories.

Table B2-1. AIS data products and typical pipeline latency				
Lev	Products	Process	Data Rate	Latency
Raw	Telemetry packets in time-stamped files	Download from SDO MOC	216 GB/dy	0
0	Spectral window images (FITS)	Unpack and sort	650 GB/dy (32 GB/dy/ln)	<2 min
0.5	Assembled (x,y.λ) cubes; SJC images (FITS)	Flat-field & align lev 0 data using SJC cross-correlation	650 GB/dy (32 GB/dy/ln)	<7 min
1	Calibrated (x,y, λ) cubes & image products (FITS)	Detailed λ cal. from table; moment-fit spectral lines	720 GB/dy (35 GB/dy/ln)	<11 min
Summary	Data-viz & summary products: JPEG images & MPEG movies with appropriate AIA images	Produce overlays with AIA; Generate periodic MPEGs	14 GB/dy	<15 min

B.2.1 Data Products & Analysis Software

AIS derived data products and analysis tools are specifically designed to interoperate with solar image data from other SDO instruments and other missions and observatories. Data product selection and design is guided by the AIS DPWG (§A.3.2), which will include members from other selected instruments and the outside community.

Level 1 data are disseminated as spectral data cubes and as derived data products: intensitygrams, Dopplergrams, line width images, and line-fit residual images for each spectral line. Data product levels, processing steps, data rates, and pipeline latencies are summarized in Table B2-1**.**

Software: Analysis software is developed at SwRI and the University of Oslo and is distributed via *solarsoft*. It incorporates both existing visualization tools and new components. In addition to batch mode pipelining tools, AIS analysis software includes a data browser (see Figures B2-1 and FO1-5), based on the SOHO `image_tool` and CDS analysis software, that allows direct visualization and local markup of data from AIS, AIA, HMI, and elsewhere. The browser is a GUI interface to the suite of pipeline software tools; it will read any FITS data with standard solar headers, though it is intended specifically for SDO data. Additional capabilities include feature tracking, line fitting, and summary plot generation using software engines that already exist. Modular, object-oriented design and software message passing allow incremental expansion throughout the mission. Design specifications will be developed during Phase A, to maximize inter-instrument coordination.

Forward modeling: A modular numerical model of the AIS instrument is distributed as part of the data analysis software, to provide a standard way to implement forward modeling of complex spectral systems. The simulated data may be run through the same pipeline that prepares actual data products, for comparison of spectral and derived data with solar models.

B.2.2 Automated Data Pipeline

The AIS pipeline is shown in Figure B2-2. AIS data are downlinked to the SDO MOC and transferred to a dedicated staging workstation, which buffers up to 1 TB (60 days) of data and downloads them to the AIS SOC over a 44 Mbps (T3) link. The T3 has over 100% bandwidth margin for retransmission of missing or garbled data. The pipeline at the SOC rapidly generates and archives level 0, 0.5, 1, and summary data.

Data in the boulder archive are duplicated at the AIS ESC in Paris via a dedicated 88 Mbps (dual-T3) line; the line has over 100% bandwidth margin after on-the-fly lossless compression.
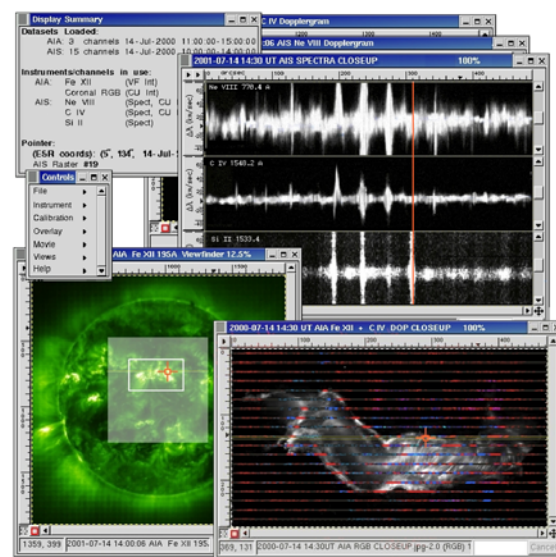
Figure B2-1. The AIS data browser allows rapid, convenient browsing through the large, heterogeneous data sets that SDO will produce.

Data quality is assured in three stages: by checksum during initial cataloguing of raw data; by statistical methods during the level 0/0.5 pipeline; and by daily human inspection of summary data at the AIS SOC. Data quality tags are included in the headers of each product.

The SOC reduction pipeline operates at >5x downlink speed to enable reprocessing if necessary. It runs on commodity workstations linked with virtual machine software such as Beowulf. Based on tests with an Athlon CPU, 10-15 *currently available* workstations can deliver 1x speed; ~20 year-2006 workstations will yield >5x speed. Pipeline software is developed at SwRI and IAS to specifications developed during Phase A.

B.2.3 Data Archive & Distribution

The complete AIS dataset is ~400 TB of raw data, and ~4 PB in total. AIS data are archived online at the SOC at SwRI/Boulder and at the ESC at IAS/Orsay, using commodity hard drives in rack-mount network-attached storage devices. Archive disks are purchased only as needed, to minimize cost as prices continue to fall. Offsite backups of the raw data are maintained in the U.S. and in France.

Data organization: Data are indexed by header fields such as time, pointing, and scan type. Database design and data interface depend on input from the SWG and other selected instruments; but an off-the-shelf database engine such as Oracle will be used. The database is developed at IAS to specifications developed by SwRI and IAS during Phase A, and verified by SwRI prior to launch.

Distribution and transport: Small data sets under 200GB are distributed via Internet; larger data requests are handled via physical media such as high-density tapes or optical disks. Data are distributed from both the SOC and the ESC. Data requests are made via an automated web form.

B.2.4 Data Analysis

Science flow is diagrammed in Figure B2-3. Team roles and experience are summarized in Table A3-3. Individual working groups guide scientific analysis for each major topic discussed in §A.3.2; working group composition and responsibilities are summarized in Table A3-2. After selection, we will work closely with the other instrument teams to ensure that joint science goals are addressed.

Figure B2-2. The AIS data pipeline produces all standard products within 15 minutes of receipt. Data products (colored boxes) are automatically archived.

Figure B2-3. AIS science flow is tightly integrated with the SDO mission and incorporates data analysis, theory, and modeling. The SOC data pipeline (dashed box) and U.S. archive are located at the SwRI SOC in Boulder, Colorado. Figure B2-2 details the pipeline.

C. Education/Public Outreach

C.1 Overview and Objectives

Solar astrophysics directly affects everyone on Earth, and outreach about solar physics is a critical part of the SDO mission and the AIS investigation. SDO is an exciting mission, and we will capitalize on that excitement to improve the teaching of science, math, and technology. The key goal is to build public understanding both of the basics of spectral measurement and of solar science. Partnerships and participation in national umbrella programs provide maximal impact for the effort expended. Targeted material on the Web – tied in to existing educational web sites – provides reference resources for the general publ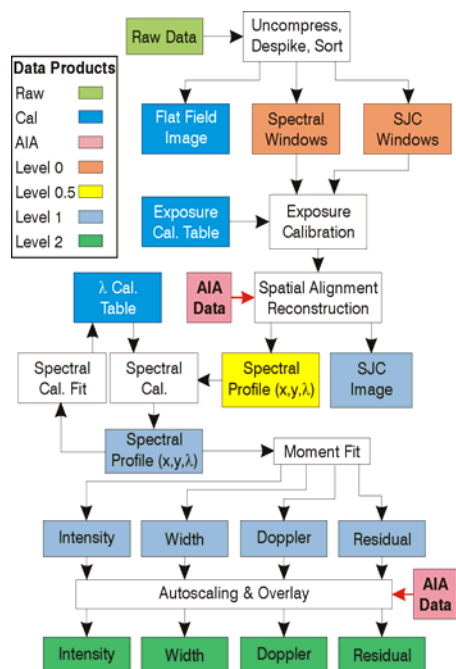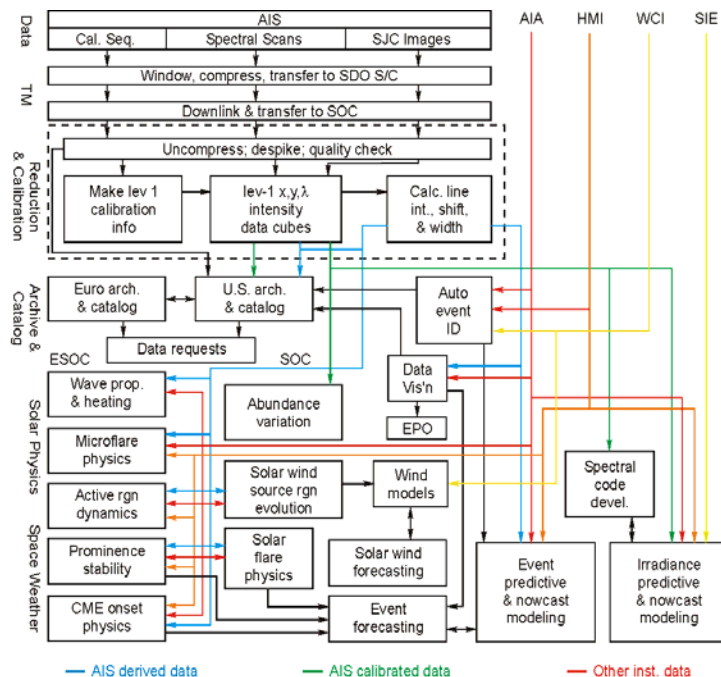ic. Teacher modules and direct contact with schools interface to the formal education system at the K14 level. Direct student involvement at the college level increases interest and directs students toward graduate school in solar physics.

The AIS EPO effort is coordinated with the umbrella SDO EPO project and leverages European and U.S. scientist time with existing EPO organizations and efforts. Detailed implementation plans will depend on the umbrella SDO EPO project; here, we present plans for AIS EPO. The PI has approved up to 5% of all paid science Co-I time to be used for EPO. One percent of the total U.S. mission cost is budgeted specifically for EPO, and an additional 2-3% will be released for EPO from reserves at launch, allowing significant augmentation of undergraduate and informal educational outreach during Phase E.

AIS EPO is planned to ramp up during I&T as reserve liens are released, and a full-time educator is supported after launch; after selection we will seek involvement from a partner institution such as Boulder's Space Science Institute. A major strength of our team is that many of our scientists have demonstrated strong interest in outreach. AIS scientists in each major region contribute to local efforts and to a different aspect of the international program. 10% of the EPO effort is spent on evaluation.

C.2 EPO Goals

The AIS EPO goals are divided by catetory of outreach: formal and informal education, and popular interest (e.g. press). They are:

Formal education:

- To provide opportunities for undergraduate physics students to participate in spacecraft operations and solar research through an undergraduate research program at each team member university and via a national outreach program for summer student internships.
- To develop hands-on learning aids of direct use for middle-school teachers who are teaching science, and disseminate those aids through existing programs such as the Sun-Earth Connection Education Forum;
- To support NASA master educators and solar scientists in conducting timely teacher workshops that use LWS science as a context for standards-based learning at the K14 level;
- To involve native Americans in research via the AIRO consortium and AIS involvement in the existing Montana and Colorado science apprenticeship programs;

Informal education:

- To develop new nodes and support existing nodes within national youth outreach programs such as Project ASTRO.
- To disseminate via the World Wide Web an educational module describing solar science and the Sun's relationship to other stars.

Popular Interest Goals:

- To publish a series of accessible popular science articles on solar spectroscopy, AIS, and the SDO mission;
- To work with existing public affairs offices to produce packaged media releases describing new results in a timely, exciting, and accessible manner;
- To collaborate with and build on existing Internet resources for outreach, such as the MSU YPOP site, focusing on making accessible the concepts behind time-resolved solar spectroscopy.

C.3 Implementation

AIS EPO focuses on three levels: formal education, public educational outreach, and popular interest. Our program leverages expertise both within the AIS team and in national organizations, and is designed to contribute to existing efforts rather than reinventing EPO infrastructure. Activities merge with operations and work within existing programs such as GEMS, SECEF, and Project ASTRO.

The AIS EPO program budget is boosted significantly by diversion of unused reserves at launch. These reserves are a major portion of the available budget during Phase E and allow significant augmentation of the effort throughout all of Phase E in addition to time contributions by participating scientists. Non-contingent funding is specifically allocated for prelaunch components that include individual scientist activities, press work, undergraduate outreach, and some funding for undergraduate fellowships.

C.3.1 Formal Education

Undergraduate operations involvement. There is a national shortage of young solar physicists, and encouraging undergraduates to enter graduate school in solar physics is crucial to the continued health of the field. The problem stems from the relatively low profile of solar physics in the academic community. AIS seeks to relieve this problem by encouraging undergraduate physics students to enter graduate school and study solar physics. Undergraduates who engage in solar physics research have been shown to be much more likely to get solar physics degrees than candidates who do not (Wills 2001), and the AIS operations plan includes a significant student component to encourage entry into the field. Students from Co-I and other universities are actively recruited for involvement in data pipeline development, data analysis, and undergraduate research. The SOC is located in Boulder near the University of Colorado campus, facilitating active student involvement. Funding for students in the operations center is drawn from the AIS operational budget and is in addition to Native American fellowships (see below).

Development of K14 course modules. After launch, 3 class modules are developed are developed by the AIS educator with input from science EPO team members and disseminated through the SECEF. The module subjects are coordinated with other efforts by the rest of the SDO project. Mason, Kucera, DeForest, and Poland have experience with classroom module design. Sample module topics include spectroscopy (including a spectroscope poster such as was developed by the successful SOHO/MDI EPO project), magnetism, and space weather.

Workshops for Master Educators. Members of the AIS EPO team will conduct short educator workshops and presentations at the annual conference of NASA's Aerospace Education Specialists (with representatives in every state). These master educators are charged with training other teachers and students all over the country. The AIS EPO team will provide curricular materials and ongoing access to solar science and space exploration expertise. Educators will gain perspective in how to teach fundamental concepts of science, math, and technology using SDO and space weather as motivational context. There is also interest in astronomy and teacher training in French and British schools, and in support of European partners a comparable workshop is held in 2008 (the year after launch). Course module development is contingent on augmented funding.

Native American fellowships. We will seek involvement with the established, successful American Indian Research Opportunities (AIRO) program at MSU and will offer undergraduate research fellowships through the program to provide scientific opportunities to students from Montana tribes. Research fellows will visit AIS science centers in Boulder, Colorado or Bozeman, Montana and participate in directed or independent research projects under guidance from designated coordinators. We will seek similar involvement with Fort Lewis College in Southern Colorado for similar contact with the Four Corners region. Baseline funding includes one summer fellowship per year during Phase E; augmented funding will support 2-3 undergraduate fellows each year of flight.

C.3.2 Informal Education

Project ASTRO. We will start at least three solar Project ASTRO partnerships with schools near AIS member institutions: in Denver, in Bozeman, MT, and in Washington, D.C. Project ASTRO benefits from ongoing relationships between the scientist partner and the school, so the SDO mission AIS provides an ideal platform to develop the partnerships. DeForest, Kankelborg, and Kucera participate in Project ASTRO.

Public accessibility of data. AIS data are made available in both scientific formats and easily viewable summary formats. The AIS web site is specifically designed to make data retrieval simple, accessible, and understandable. AIS data are exported to major solar web sites such as the SDO main site and other observing sites. An "Image of the week" page with an interesting AIS image and popularly accessible commentary is produced weekly and posted on the web site.

Table C1: AIS E/PO Team Members & Roles		
Scientist	Experience	EPO Role
Ayres University of Colorado Boulder, Colorado	Popular lectures, popular science writer; educational experience	Undergraduate research & Front Range regional lead
Brekke ESA at NASA/GSFC College Park, Maryland	SOHO/ESA EPO lead; web design; K14 EPO; media appearance	ESA EPO lead
DeForest SwRI Boulder, Colorado	AAS/SPD press officer; popular writing; educational policy; media appearance	Press contact; EPO coordinator
Kankelborg MSU Bozeman, Montana	popular lectures; science fairs; public Q&A for "Dr. SOHO"; YPOP contact	Montana regional lead
Kucera NASA/GSFC, College Park, Maryland	SOHO EPO; popular lectures & writing; K14 EPO; media appearance	GSFC EPO lead
Poland NASA HQ Washington, D.C.	SOHO EPO; K14 EPO.; science fairs; science contests; media appearance	D.C. regional lead
Mason Cambridge University Cambridge, U.K.	SOHO EPO; SunTrek project; K14 EPO; press & popular writing	UK EPO lead

C.3.3 Public Outreach

Popular Science Articles and Lectures. Several Co-Is contribute regularly to popular science magazines such as *Astronomy* and will author articles about spectroscopy, space weather, and plasma physics. AIS team members will give public lectures at associated universities, musea, and planetaria.

Media Packages. DeForest, Poland, Brekke, and Mason are all experienced at generating press packages. DeForest is the press officer of the AAS/SPD and will prepare press releases and packages for the mainstream news media as appropriate.

An Education Website. on basic solar physics and spectral imaging is designed by the AIS Educator with input from the science team. The website is integrated with existing solar projects such as YPOP. Members at all institutions have extensive experience with educational web pages such as the Solar Center, the Dr. SOHO pages, the SunTREK project, and YPOP. The level of effort devoted to the web site depends on whether funding is augmented in Phase E, but even with only baseline funding we will support both an YPOP site and the umbrella SDO web site.

C.4 Assessment / Evaluation

Assessment and evaluation of activities are crucial to successful educational activities. Each AIS educational activity includes an associated evaluation component to provide feedback, direction, and evaluation. Specific assessment protocols are developed during Phase A.

C.5 Team E/PO Qualifications

Our team members have demonstrated strong commitment and ability in public outreach. The "conventional wisdom" is that spectroscopy is challenging to communicate, but our team includes highly motivated and qualified communicators who have demonstrated ability to convey he excitement of newsworthy spectroscopic results. PI Hassler's "Source of the Solar Wind" news release was the most popular spectroscopic news story in over a decade, receiving international media attention and winning a spot on the CBS Evening News. Co-I DeForest is the press officer for the AAS/SPD and press liaison for Solar and Heliospheric Physics within NASA/OSS, and participated in development of national space science education and outreach policy via the recent Decadal Survey activity.

The AIS educational team is extremely strong and leverages existing infrastructure and institutional expertise. Drs. Mason, Poland, and Kucera have strong experience and interest in formal and informal educational outreach. Montana State University has a rich history of instructional innovation and educational research in addition to significant experience with mission-level E/PO projects such as the Yohkoh Public Outreach Project and the E/PO programs for SOFIA, SIRTF, and MESSENGER.

D. Technology and Small Disadvantaged Business/Minority Institution Plan

D.1 Background and Commitment

The AIS team will work with the SDO project to successfully transfer technology developed on AIS for use in the public sector. SwRI has an existing, long-term commitment to Technology Infusion and Transfer, as demonstrated by these direct quotes from the SwRI Operating Policies and Procedures (OPP):

"*SwRI is an independent, non-profit, applied engineering and physical sciences research and development organization dedicated to technology development and transfer.*"

"SwRI specializes in *the creation and transfer of technology in engineering and the physical sciences.*"

As an independent, non-profit research and development organization, the overriding culture of SwRI since its inception has been to exploit existing technology, to infuse that technology into a project, to advance the maturity level of technology, and *ultimately to transfer that technology to the public at large*. Recent examples of technology transfer include an SwRI-developed data file and display system (software invention reports MFS-31325-1 and MFS-31327-1), and 24 SwRI-led projects that have won "R&D 100" awards (7 in the last 5 years).

D.2 The Fit between AIS and OSS Technology Transfer Strategy

The AIS development will directly address five high priority needed technologies identified in the Office of Space Science (OSS) Enterprise Integrated Technology Strategy: 1) advanced optical systems with high-precision controls, 2) new sensors and detectors for telescopes, interferometers, and remote and *in-situ* instruments, 3) coolers and other instrument support systems, 4) advanced miniaturization and ruggedization of electronic and mechanical components, and 5) lightweight, multi-functional structures. Furthermore, the AIS development addresses eleven of the technology needs of the current OSS technology program: 1) lightweight optically precise structures, 2) advanced lightweight materials, 3) collaborative design infrastructure, 4) verification and validation, 5) optical control systems, 6) ultraviolet, visible and infrared sensors, 7) spectrometer and radiometer

systems, 8) ultrastable structures, 9) power conversion, 10) instrument and spacecraft computing systems, and 11) autonomous science algorithms and architectures.

D.3 AIS Technology Infusion

The development character of AIS includes the infusion of technologies developed for other space missions as well as technologies from the commercial sector. For example, Alenia (Italy) has enabling technologies in scanning and jitter control mechanisms that will enable AIS to take advantage of the high reliability / high precision Hexapod / PZT scan/jitter control mechanism developed for SAGE-III. The mechanism allows AIS to scan the primary mirror about the telescope focus point while maintaining high image quality over a wide scan angle. The RAL/MSSL highly integrated, low power CCD array and electronics package being used for the AIS cameras is a case where dual-use technologies (CCD technologies have applications both in the space program and in the private sector), is being infused into a number of space programs. It should also be noted that there is substantial European technology that is being infused into the AIS project that will have later US applications. Additional advanced technologies that are being infused into the program to fulfill the AIS requirements include:

- State-of-the-art optical coatings and low-scatter optical polishing techniques (high reflectivities w/multilayer coatings in the EUV; <5 Å rms surface roughness).
- Instrument structure made from graphite-epoxy composite materials to minimize thermal expansion and contraction, parts count, fastener mass, number of joints and maximize stiffness.
- Highly capable (20 MIP, 5 MFLOP) rad-hard SPARC processor provides unprecedented processing capabilities for a flight UV spectrograph.
- The use of data pipelining technologies to provide high performance and highly optimized algorithms and visualization techniques for the large amount of data to be captured by AIS in the five year mission.

D.4 Future AIS Technology Transfer

Specific areas of technology developed for SDO AIS that are candidates for technology transfer and further development for industrial and commercial applications include:

1) AIS itself is a wide field of view imaging

spectrograph with potential use in hyperspectral surveillance imaging, pollutant monitoring, and jet engine exhaust and flame studies.

2) Robotics in many industries can make use of the 6 degrees of freedom afforded by the Hexapod scan/jitter control mechanism that has closed loop high-precision pointing.

3) High radiation tolerant ICCDs have imaging applications in the field of nuclear medicine.

4) Improved optical mounting systems and low-CTE structures have already benefited other NASA missions, and are good candidates for more intensive infusion/technology transfer.

5) High performance data pipelining and visualization techniques a myriad of potential uses in the medical, petroleum, and chemical industries—applications where one has to handle, examine, correct, and store large amounts of data could use AIS processes.

We are excited to foster SDO-derived instrumentation advances and applications such as these to benefit the U.S. industrial sector. Additionally, we expect that other technology transfer areas will be identified during the AIS development that can be exploited as well.

D.5 Technology Transfer and Commercialization Plan

In concert with SwRI's charter, SwRI will contribute services with the sole purpose of implementing the transferal of AIS technology to NASA missions, and to foster commercial and military applications. Equally important, the AIS team will work with GSFC and the SDO project to leverage the AIS technology transfer/infusion efforts with the larger project and field center plans. Dr. William Lewis of SwRI will report directly to the AIS PI and PM to transfer AIS technology in an efficient and timely manner.

Several methods that we plan to use for technology transfer on the AIS program include:

1) Publishing technical and scientific papers and presenting papers at technical conferences.

2) Publishing semi-technical articles in popular technology magazines, and journals.

3) Taking advantage of our existing publications that focus on technology transfer: NASA Tech Briefs, SwRI Technology Today, etc.

4) Presenting technology innovations at industrial trade shows and conferences.

5) Tying the AIS technology transfer/infusion activity to the AIS E/PO activity to generate a multiplicative effect between our public outreach and technology transfer efforts.

6) Presenting talks and briefings, as appropriate, to the public through the general print, radio, and TV media, as well as in local venues such as science museum and planetarium lectures.

The AIS team will present our plan for technology infusion and transfer at the AIS PDR. This plan will include the following action areas:

1) Identifying AIS technologies that are of interest to outside partners.

2) Identifying outside markets, industries, partners that could use AIS technology.

3) Obtaining teaming agreements with outside organizations that desire AIS technology.

4) Working with and leveraging the AIS effort with GSFC and NASA's network of National and Regional Technology Transfer Centers.

5) Implementation of the transferred technology.

D.6 Small Disadvantaged Businesses

SwRI is committed to a proactive program of small and small disadvantaged business participation in the AIS mission with a project goal of 8%. We plan to seek out qualified and interested SWHMs[1] through our ongoing relationship with the San Antonio and Denver offices of the SBA, and through constant review of purchase orders and subcontracts. Locally, we will solicit lists of qualified vendors and businesses with the San Antonio Hispanic Chamber of Commerce whose charter is to help the primarily Hispanic small businesses of San Antonio. The SwRI purchasing department has designated an individual (Mr. Paul Easely) to serve as the SWHM liaison for the AIS mission. He will review all AIS purchase orders and subcontracts for possible SWHM participation. On a monthly basis, he will attend the AIS management telecon to be apprised of the project status and upcoming activities. SwRI will work with the other AIS teammates to maximize their use of SWHMs.

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[1] SWHM includes: small disadvantaged business, women-owned business, historically black colleges, and minority institutions

E. Management, Schedule and Risk Management Plan

E.1   Introduction

The AIS management team brings to the SDO program personnel experienced in both instrument development and management practices successfully proven on recent MIDEX, Discovery and other NASA and ESA programs. The AIS team is led by Southwest Research Institute (SwRI), home of the Principal Investigator (Dr. Don Hassler), and is assisted by several other institutions that are experts in solar spectroscopy instrumentation. SwRI recently managed the successful IMAGE MIDEX program to an on-time and under-budget delivery, and recently delivered to the ESA *Rosetta* program the *Alice* UV Spectrometer and the Ion Electron Spectrometer (IES). Over the past three decades, the other lead AIS institutions have contributed to IMAGE, HST, TRACE and *Rosetta*. Importantly, the majority of the members of the AIS team directly contributed hardware and software for the SOHO SUMER, CDS, UVCS and Solar-B/EIS UV spectrometers, and are still actively using the SOHO instruments for data analysis and solar studies. The AIS team has taken the lessons learned from building, testing and using both the SUMER and CDS instruments on a day-to-day basis to develop and optimize the AIS to maximize science return and minimize risk to SDO. The AIS management structure is set up to provide simple, clean lines of authority and accountability. We have included a strong, experienced system engineering team to ensure that AIS requirements are not only identified but documented, tracked and verified. The AIS team is experienced with the difficulties in managing a multinational team and has established an organizational structure that directly addresses this both programmatically and technically. Because of the experience of our management and system engineering team and the well-proven processes and metrics to be used in the daily management of the AIS project, we have absolute confidence in the ability of the team to deliver on time, and within budget, while meeting or exceeding all AIS measurement requirements.

E.2   Management Approach

Our management approach is based on the successful practices recently used on IMAGE and the *Rosetta Alice* program. Performance metrics originally developed for IMAGE, then augmented and improved upon for *Rosetta Alice*, will be used to track technical, schedule and budgetary progress. The SwRI-led project management team provides resources, coordinates, and oversees the work of all team members to ensure their finished products meet performance and quality requirements to realize the AIS project objectives.

Key elements of our management approach include: 1) define a set of achievable science objectives, 2) assemble a team of experienced, talented and dedicated scientists and engineers to implement the project, 3) provide clear technical and programmatic requirements to each team member based upon a systems engineering flow down process, 4) establish a clean organizational structure with clear lines of authority and oversight responsibility, 5) allocate and track resources (technical, budget and schedule) of each subsystem and team member based upon AIS instrument requirements, 6) implement a comprehensive peer and milestone review process, 7) apply reliability engineering practices (WCA, FMEA, FTA) at the beginning of the project and continuously update those analyses as the AIS development matures, 8) implement a comprehensive systems engineering process, 9) start the program with ample reserves / margins (technical, schedule and budget) and track and issue those reserves on an as-needed basis to reduce risk, 10) implement a thorough risk management process that continuously evaluates project risks and provides linkages to mitigation plans, and 11) manage the team through good communication and reacting to problems as they first occur. All of these actions and processes are in place and will be described below.

E.3   Team Organization

The AIS organizational chart is shown in Figure E3-1 with organizational responsibilities, points of contact, and experience. See also Table A3-1 for a detailed listing of subsystem responsibilities. The organizational structure was designed to have a tight coupling between the Principal Investigator (PI), Project Manager (PM), and the Project System Engineer (PSE) for the management of science, programmatic and technical requirements, respectively. Subsystem managers for each of the major system components have been defined. It is their responsibility to lead the development of their respective subsystem within schedule and budget while meeting their respective technical requirements. Experienced Lead Systems Engineers to oversee U.S. and
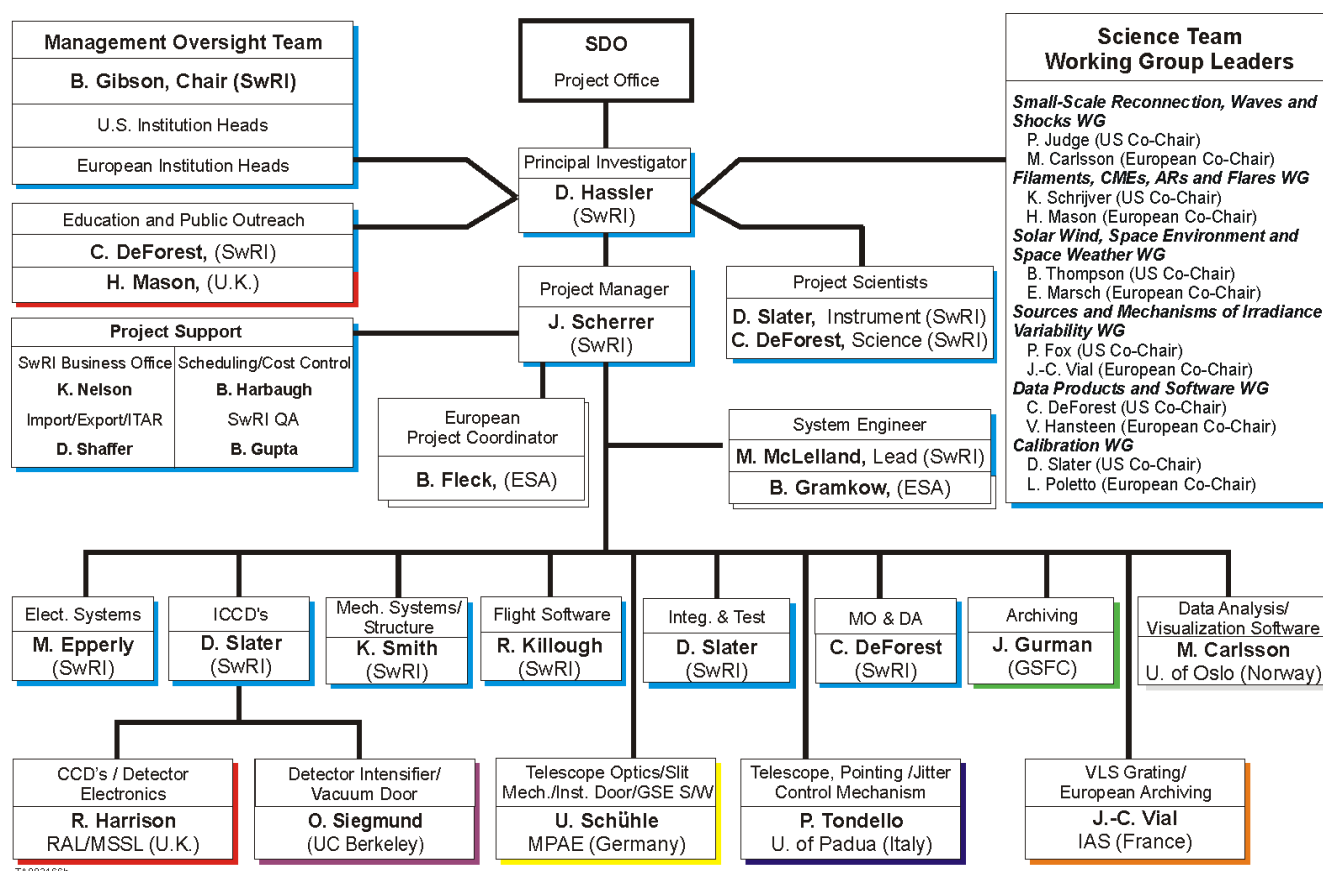
Figure E3-1. The AIS organizational structure provides clear lines of authority and oversight

Table E3-1. AIS Team Member Institutional Experience and Responsibility			
Institution	**Mission Responsibility**	**Point(s) of Contact**	**Institutional Relevant Experience**
Southwest Research Institute (SwRI)	• Overall AIS program, science, technical management, and system engineering • AIS C&DH, HVPS, LVPS • AIS optical design, mechanical specification, integration, test, and calibration • MO-DA, E/PO	Dr. Don Hassler, PI Mr. John Scherrer, PM	IMAGE MIDEX Mission, Medium Energy Neutral Atom Imager (MENA), UARS/Particle Environment Monitor (PEM), *Cassini*/*Cassini* Plasma Spectrometer (CAPS), DS-1, Plasma Experiment for Planetary Exploration (PEPE), *Rosetta*/Ion Electron Spectrometer (IES), Rosina, *Alice* UV Spectrometer, New Horizons
Max Planck Institute für Aeronomie (MPAE)	• Telescope optics • Slit changer mechanism • AIS instrument door • GSE software • PTB calibration source	Dr. Udo Schühle	SOHO/SUMER, NIXT, SOHO/LASCO, *Rosetta*, STEREO/SECCHI
Institut d'Astrophysique Spatiale (IAS)	• Variable line spaced grating • European data archive	Dr. Jean-Claude Vial	SOHO/SUMER, Solar Max UVSP, PHOBOS IPHIR
Rutherford Appleton Laboratory (RAL)	• Detector electronics	Dr. Richard Harrison	SOHO/CDS, Solar-B/EIS
Mullard Space Science Laboratory (MSSL)	• CCD procurement • CCD Detector Testing	Dr. Len Culhane	SOHO/CDS, Solar-B/EIS
University of Padua	• Optical design • Pointing and jitter control mechanism • AIS Telescope integration	Dr. Pino Tondello	SOHO/UVCS
University of Oslo	• Data analysis software • Visualization and quicklook software	Dr. Mats Carlsson	SOHO/SUMER, CDS, Solar-B/EIS
University of California Berkeley (UCB)	• Detector intensifiers • Detector vacuum door	Dr. Oswald Siegmund	IMAGE MENA, FUV-SI, FUV-WIC, *Rosetta Alice*, FUSE
Goddard Space Flight Center (GSFC)	• Data archiving	Dr. Joe Gurman	SDAC, SOHO, TRACE, SMM, STEREO, Solar-B

European activities have already been identified and assigned to work with the AIS institutions to communicate and ensure verification of technical requirements, work technical trades, and most importantly, lead the AIS Risk Reduction Team (RRT). The PSE's will support the management team and will have a prime focus on minimizing project risk to ensure the technical success of AIS.

The AIS project has a very strong international team with a high level of participation by our European partners. This high level of participation shows that they are committed to the SDO project and in the need for including the AIS spectrograph on the SDO mission. The AIS' high level of performance would not be possible without the strong participation of our teammates.

Principal Investigator (PI): Dr. Don Hassler (SwRI) will serve as the AIS PI. He is head of the Solar and Stellar Physics Group of SwRI. Dr. Hassler has been either Principal Investigator or Co-Investigator on seven sounding rocket flights and participated in the first successful flight of Ultraviolet Coronagraph Spectrometer (UVCS) on the Spartan 201 Space Shuttle Experiment (STS-56). He is a funded Co-Investigator with the SUMER instrument and an Associate Scientist with the CDS instrument on SOHO, and is a funded Co-I with the STEREO/SECCHI Team. He is also a member of the NASA ILWS Solar Dynamics Observatory (SDO) Science Definition Team, the 2002 NASA Sun-Earth Connection Roadmap Committee and the ESA Solar Orbiter Remote Sensing Working Group. Dr. Hassler will have direct accountability to the NASA SDO project office for the implementation of AIS. The AIS Science Team, Education and Public Outreach (E/PO) effort, AIS Management Oversight Team (MOT), Project Scientists and the AIS Project Manager will report directly to Dr. Hassler. As PI, Dr. Hassler will be responsible for the overall success of the AIS project. He will lead the science team in establishing science objectives, overseeing the construction, testing, calibration and integration of AIS, and planning science observations, data reduction, analysis and archiving. He will also serve as the ultimate decision making authority on the allocation of resources.

Project Manager (PM): At the request of the PI, Mr. John Scherrer (SwRI) will manage the day-to-day activities of the AIS project. He will be directly responsible for cost and schedule development and tracking. Mr. Scherrer will serve as the point-of-contact to the NASA SDO project office for all management matters, and Mr. Scherrer will interface and consult with the project SE lead (PSE) for all risk management, systems integration, and systems engineering matters. Mr. Scherrer is currently the Project Manager of the *Rosetta Alice* UV spectrometer. Mr. Scherrer was the Deputy Project Manager of the IMAGE program, the first NASA MIDEX mission, and is now a Senior Project Manager in the Space Science and Engineering Division at SwRI. As shown in Figure E3-1, the European Project Coordinator, the AIS subsystem leads, and the SE team will report to Mr. Scherrer. Mr. Scherrer reports directly to the PI.

European Project Coordinator (EPC): Dr. Bernhard Fleck of ESA will serve as the AIS EPC. Dr. Fleck's current position is SOHO Project Scientist and in this role he has served as the liaison to the US PI teams on the mission. On AIS, Dr. Fleck will report directly to the PM and will serve as a coordinator for European AIS activities and reviews. Dr. Fleck's "on site" presence will help to identify problems in their infancy when they are easy to solve and will reduce AIS programmatic risk.

System Engineering Team: Mr. Mike McLelland (SwRI) will serve as the lead Project System Engineer (PSE). Mr. McLelland is currently the project manager for the development of avionics for the NASA Swift mission and the deputy project manager for the *Rosetta* IES instrument. As the PSE, Mr. McLelland will be responsible for the identification and control of all AIS technical interfaces; the allocation and tracking of AIS mass, power, and telemetry resources; coordinating the identification, documentation and verification of all AIS technical requirements; and lead the AIS RRT. He will oversee the technical interface between the AIS instrument and the SDO spacecraft. Mr. McLelland will serve as the lead engineering team member in the overall development of the AIS instrument. He will be responsible for overseeing the development of all AIS technical specifications and interface control documents, and the implementation of the relational database that will be used to ensure linkage between AIS science objectives and technical requirements.

Mr. Bodo Gramkow of ESA will assist Mr. McLelland in AIS system engineering tasks. Mr. Gramkow is currently the lead instrument system

engineer on the ESA *Rosetta* project and will bring to the AIS team years of experience interfacing with European institutions. As with the European Project Coordinator, Mr. Gramkow's "on site" presence will greatly enhance the efficiency of communication about technical details.

Science Team: The science team will be led by and report directly to PI Hassler. During the development phase, it will be the Science Team's responsibility to ensure that the AIS hardware and software meets the AIS science objectives. This team will provide feedback during the design phase to optimize the science return while minimizing program risk. They will be involved in the decision-making process concerning design and manufacturing trade-offs that have a direct effect on the scientific measurements. During the calibration phase, the science team will be directly responsible for analyzing the instrument data and verifying that the AIS measurement requirements are met. Science Team activities, Co-I responsibilities, the organization of the Science Team, and its experience are summarized in Table A3-3.

Management Oversight Team (MOT): The MOT is comprised of heads of all of the U.S. and European institutions. Their primary responsibility is to ensure that the needed resources (i.e. personnel, facilities, etc.) in their institution are available so that the AIS development is not hampered by outside influences. Included in Appendix 1 are Letters of Commitment from these institution leads expressing their endorsement and strong support for the AIS project. Mr. Bill Gibson, Assistant Vice President at SwRI, will serve as the chair of this team. Mr. Gibson was the Project Manager of the successful IMAGE MIDEX mission and has a wealth of insight into instrument development programmatic issues and problem solving. Standing quarterly meetings / telecons will be held between the AIS management team and the MOT to identify and fix institutional problems affecting the AIS development. The MOT will also be invited to attend all AIS reviews.

Just after award, the AIS project and the SDO Project Office will jointly select a separate technical and programmatic review panel composed of experts in instrumentation development. In accordance with NIAT recommendations and for project continuity, this panel will serve as the review panel for all AIS formal reviews.

E.4 Approach for Combining with LMSAL/AIA Team

During the proposal stage, we have had discussions with personnel from LMSAL who are proposing the SDO investigation called AIA, with Dr. A. Title as PI, for possible collaborative developments. For example, the LMSAL/AIA and AIS flight instrumentation might be operated from either the same, or an identical, C&DH system, and/or a common ground data handling system might serve both investigations. Dr. A. Title is an Associate Investigator on AIS and Dr. D. Hassler is a Co-Investigator on the LMSAL/AIA investigation. If both AIS and LMSAL/AIA are selected, we will work with Dr. Title's team during Phase A to establish (and propose) the overlaps we determine to be programmatically and scientifically beneficial. Cost savings for such synergism have not been estimated as part of the present proposal but would be significant.

E.5 ITAR and Import/Export Concerns

The AIS investigation benefits significantly from the support of our European team members. With the advantages of European support comes the extra challenge of managing an international team and complying with ITAR. The experiences of managing the IMAGE project, which included five international partners (along with 19 subcontractors); *Cassini* CAPS, which included five international team members; and SEPAC/Spacelab with extensive Japanese involvement, has prepared us well to manage the AIS project. SwRI is very familiar with the problems of complying with the International Traffic in Arms Regulations (ITAR) law, the associated US Munitions List and the import and export regulations. SwRI has been registered as an exporter with the Office of Defense Trade Controls since 1977. Ms. Debbie Shaffer will serve as the AIS Import/Export/ITAR lead. Ms. Shaffer has been dealing with U.S. import/export federal regulations for more than 7 years. She recently hosted a national seminar titled "Export and Licensing Requirements for Space Based Programs" that was attended by over 70 university, commercial, legal, and NASA import/export professionals. In addition, she has been an invited speaker on ITAR issues at several other national conferences. SwRI as a contractor with per year revenue in excess of $300M with a significant portion devoted to defense activities, deals with ITAR issues on a daily basis. We have developed

and negotiated hundreds of Technical Assistance Agreements (TAA) with the US Department of State and because of the nature of our work, we must remain current on all the latest regulations and requirements. We have implemented the provisos of TAAs with Technology Export Control Plans (TECP). We have worked with Code I at NASA Headquarters on numerous Memorandums of Agreement (MOA) and Memorandums of Understanding (MOU). Finally, we have worked directly with multiple European research institutes to develop MOUs and Interface Control Documents (ICDs). For non-ITAR sensitive items, SwRI has experience in dealing with the Commerce Department in negotiating export licenses. SwRI has arrangements with international shipping brokers for the preparation of carnets and other documentation for shipment of equipment to and from Europe.

To ensure that AIS can proceed immediately upon selection, we have already completed TAA's for activities with all of our European partners. They are in the signature process, and will be submitted by May 24, 2002, ensure the approved legal dissemination of AIS information from the time of contract award. See Appendices 5 and 6 for more details regarding foreign participation including copies of the submitted TAA's.

E.6   Team Communications

The AIS management team (PI, PM, PSE) are all members of the SwRI Space Science and Engineering Division. The PI is located in the SwRI-Boulder office while the PM and PSE are located in the SwRI San Antonio (SwRI-SA) office. SwRI-Boulder will be the center of AIS scientific activities, and SwRI-SA will be the center of AIS instrument activities. This arrangement builds upon the natural strengths of each location, benefiting from the strong solar physics community in Boulder and the hardware expertise at SwRI-SA. During the critical hardware phase (C/D) of the mission, Dr. Hassler will reside in and spend the majority of his time in SA. A standing weekly telecon will be held between the management team, the EPC, ESE, and each of the subsystem leads to discuss technical and schedule status. The SDO project office is invited to take part in these telecons. An additional standing weekly telecon will be held with the system engineering team led by the PSE to discuss technical trades, resource status, and risk reduction. The SE telecon will include other technical experts

on an as needed basis. A third biweekly telecon will focus on minimizing AIS risk, and will be attended by members of the AIS RRT led by the PSE. We have recently upgraded the teleconference facilities in both the SwRI Boulder and San Antonio offices; these facilities will be available to the AIS team whenever needed. Quarterly to bi-annual meetings (depending on project phase) will be held on site at the European hardware and software institutions to verify technical and schedule status. SWGs, meetings with the SDO Project Office, the launch vehicle team, and the launch site have also been included in the AIS budget. A narrative monthly progress report will be the formal means of communicating status to NASA and AIS team members.

The AIS project will utilize the existing web-based, SwRI-developed, Action Item Management System (AIMS) for use on the *Cassini* program, and subsequently used on our *Rosetta*, IMAGE, and New Horizons projects to track action items generated at reviews and meetings. The system provides a database of the action items and automatically emails the actionee until the action is formally closed by the PM. The NASA SDO Project Office will have full access to the database to keep apprised of the status of AIS action items.

E.7   Decision Making Process: PI, PM and PSE Roles in Decision Making

Our goal is to minimize project risks of all types, and to efficiently manage the project. Management decisions will be made by the senior management team, consisting of the PI, PM, and PSE. The PI, however, is always the ultimate decision-making authority.

E.7.1   Resource Allocation Decisions

Margins (technical, budget, and schedule) will be managed at the AIS project level. Individual subsystem leads will manage their respective reserves. The PSE is the principal decision-maker for technical resources. The resource budgets will be tracked and trended over time to ensure that the remaining margins are consistent with the plan. If the need arises to change technical resource allocations, that decision will be made by the PSE. The PM, with approval from the PI, controls budget and schedule reserves.

E.7.2   Cost and Schedule Decisions

As noted above, decisions relevant to schedule and cost are made by the PM with recommendations from the PSE. Should a decision require the release of cost or schedule

reserve, the PM will provide his recommendation to the PI for approval.

E.7.3 Performance Decisions

Decisions relevant to integrated instrument or subsystem performance will be made by the PI in consultation with the PM, PSE, and the relevant subsystem lead. (The science team will be consulted for decisions that effect science objectives). Decisions concerning individual subsystems that do not affect external interfaces, performance, or resources will be made by the group responsible for that subsystem, reporting the decision to the PI and PM through the PSE.

E.7.4 Descope Decisions

§E.13.5 provides a discussion of AIS descoping, including a preliminary list of descope options. If reserves (technical or programmatic) are required beyond the planned release level, the evaluation of the need for a descope will be triggered. Should a descope decision have to be made for either technical or non-technical reasons, the PI, after conferring with the Science Team, the appropriate subsystem lead(s), and the PM, will make a recommendation to the NASA SDO Project Office.

E.8 Resource and Margins/Reserves Management

E.8.1 Technical Resource Allocation

Technical resources (e.g., mass, power, telemetry, CPU cycles, volume) are assigned to each subsystem by the PSE at the start of the project. Reserves are allocated to each subsystem based upon maturity. Subsystem leads control their individual reserves reporting their status to the PSE. All margins are held at the AIS project level and can only be used with AIS management team approval. We based our proposed AIS resource allocations on developed heritage systems supplemented by engineering models as necessary. Should a subsystem manager require a change in resource allocation, he/she will do so through an Engineering Change Request (ECR) to the PSE.

E.8.2 Resource Tracking

The PSE maintains the technical resource database for the project. The basis of this database is not simply the month's current best estimate (CBE), but a combination of the CBE and a maturity factor. The maturity factor will be based on the state of development of the component. For instance, a resource CBE that is based strictly on an unsupported estimate is given a maturity factor of 1.25, meaning that the estimate is no better than

25% accurate. For CBEs based on calculated values, the factor falls to 1.15. Only for those resource allocations based on actual measured values will the maturity factor attain 1.0. The PSE's monthly resource updates will be included in the project monthly technical progress report.

E.9 Margins and Reserves Strategy

The current maturity based reserves held by the AIS project are detailed in FO-2. The overall mass reserve is a conservative 26% (11.5 kg). Power is likewise conservative with a reserve of 19% (9.4 Watts) being carried at end of life. The seven-month schedule margin (see Figure E9-1) derives from 4 months of margin prior to instrument integration for the longest lead subsystems, and 3 months of margin prior to instrument delivery.

The allocation of reserves is an important element in risk management. Throughout the AIS development, decisions will be made by the AIS management team to determine if risk can be mitigated by releasing mass, power, budget or schedule reserve. Releasing reserve will be dependent on the maturity of the program at the time and the perceived risk of the activity. Technical margins will only be released through approved ECRs.

E.10 Systems Engineering Process

System Engineering has three main responsibilities: 1) the verification of technical requirements, 2) the management of technical resources, and 3) the oversight and control of system interfaces and trades. For AIS, we are going a step further. The System Engineering team will also have the overall responsibility for the AIS Risk Reduction program. Each lead hardware producing institution will appoint a System Engineer (SE) that will interface directly with the PSE and lead European SE and will have the primary responsibility for being the single point of contact at his/her institution for AIS technical matters.

One of the first duties of the SE team will be to draft the AIS Instrument Performance Specification (IPS). As on IMAGE and now on Deep Impact, the verification of IPS requirements will be tracked using an on-line verification database. All AIS technical requirements from component through system level will be input into the database. The project–wide database will produce reports stating the requirement, how it is to be verified, the test procedure, where it will be
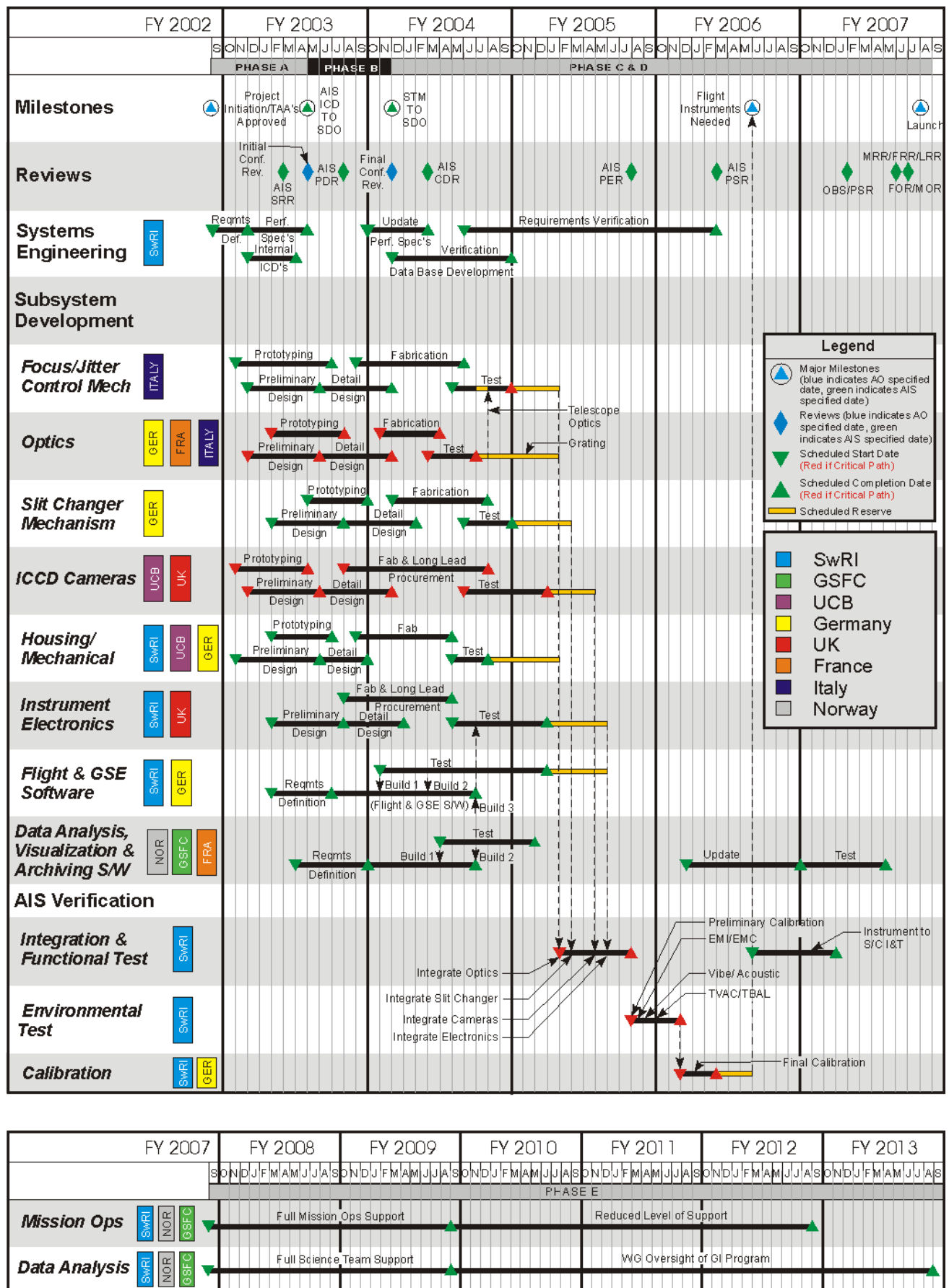
Figure E9-1. AIS schedule has 7 months of contingency.

verified, and the status of the verification. The database provides true flow-down and closure of all AIS technical requirements. The PSE at SwRI will lead the effort in maintaining the database and the planning of the AIS verification and test program.

The management of technical resources will also be performed as it was on IMAGE. The PSE will have the responsibility for tracking and allocating technical resources including mass, power, data rate, and memory. The PSE will control the release of technical reserves through the use of ECR. The release of reserves will be tied to a schedule based upon project and instrument maturity. The approval of release of reserves in excess of the planned schedule requires both PM and PI approval. The SE team will also manage, document and control all system interfaces and trade studies. Released and controlled Interface Control Documents (i.e., electrical specifications, mechanical and thermal interface control documents) will govern all interfaces. Changes will only be made with approved ECR's. All trade studies will result in either a report or memorandum documenting the findings and conclusions of the study. These reports (after screening for ITAR issues) will be placed on the password protected AIS Project Web site for easy access by the distributed team.

E.10.1 Mission Assurance

The process to maximize the probability of meeting the science objectives is the prime responsibility of the SE team. Reliability analysis based on part count, Worst Case Analysis (WCA), Failure Modes Effects Criticality Analysis (FMECA), and Fault Tree Analysis (FTA) will all be initiated under the oversight of the SE team in Phase A. The quantitative results from these analyses will be used to determine what changes to the AIS design have the most leverage for improving the likelihood of mission success. "What If" analyses will be performed during Phase A that will include looking at screening requirements, part levels, redundancy and cross strapping to minimize risk within project resources (mass, power, cost, etc). These analyses are not static — the SE team will have the responsibility for updating and maintaining these analyses throughout Phases B and C/D to reflect the as-built configuration. See §E.13 for a description of the planned AIS risk management activities.

E.10.2 Heritage and Maturity of Mission Elements

One of the prime methods of reducing program risk both technically and programmatically is through the use of heritage components. AIS has been configured to maximize heritage from previous missions, such as SOHO/SUMER, SOHO/CDS, TRACE, *Rosetta Alice*, HST/COS, SAGE III and SOHO/UVCS. Table A3-1 lists the AIS subsystems and their heritage.

E.10.3 Approach to Use or Nonuse of Redundancy and Other Reliability Management Issues

AIS is in general, a single string instrument. During Phase A, the use of redundancy to enhance instrument reliability will be investigated using quantifiable reliability calculations. AIS will achieve maximum mission reliability through design simplicity, high reliability parts, integrated testing and the development of the instrument by experienced institutions with proven track records. The AIS project will use an integrated and proactive reliability program.

E.10.4 Product Assurance

AIS will maintain a Product Assurance and Safety Program that is structured to ensure a highly reliable and safe program at the lowest possible risk and consistent with the ILWS Mission Assurance Requirements (MAR) document. The AIS program will be based on ISO 9001 quality system requirements and will embrace the interrelated disciplines of Reliability, Electrical, Electronic, and Electromechanical (EEE) Parts; Materials and Processes (including Contamination Control); System Safety; Hardware Quality Assurance; and Software Quality Assurance. Our Product Assurance and Safety program will be fully defined in our Product Assurance and Safety Plan that will be prepared immediately following contract award. The plan will be embraced across the AIS program with tailoring for each institution's standard operating procedures.

Key elements of our Product Assurance and Safety program include maximizing the use of proven and reliable parts, materials and processes; ensuring design margins (including those for contamination); ensuring that hazards to personnel, equipment, and facilities are eliminated or controlled to acceptable levels of risk; emphasizing design simplicity; verifying software is consistent,

correct, and complete; maintaining a disciplined and aggressive closed-loop failure reporting, analysis, and corrective action system; and implementing proven quality controls to assure the AIS hardware is reliably manufactured in strict accordance with its engineering documentation. The effectiveness of these measures are determined and supported by design analyses, formal design reviews, peer reviews, hardware tests, and failure data evaluation.

Our EEE parts program ensures parts function reliably for the necessary mission design life and environment. Under this program, parts selection, screening, and qualification are per the requirements of a Level 2 program as defined in GSFC-311-INST-001, Rev. A. This program includes an evaluation of part history, a review for radiation hardness, a Parts Control Board (PCB), GIDEP reviews, and DPA on selected active parts.

E.11 Project Schedule Development, and Schedule and Cost Tracking

The master schedule for AIS, referenced to a August 2007 launch (see Figure E9-1), contains significant margin: 7 months total, including 4 months prior to instrument integration based upon the longest lead time instrument subsystem and an additional 3 months just prior to instrument delivery. We will use our project status metrics system that is based upon a project-wide schedule in Primavera Project Planner (P3) and custom reports to provide management insight into schedule and budget metrics. The AIS management team used the same system on the successful *Rosetta* and IMAGE projects. The following sections describe the schedule/cost development and tracking process that will be used to manage the AIS project.

The AIS development schedule currently has two critical paths (when critical path is defined as the path with the minimum schedule margin). The first path flows through the telescope optics developments to their integration with the scan/jitter control system to AIS integration and test. The second path contains the development of the intensified CCD cameras and again through AIS integration and test. While both of these paths currently have the least margin (~7 months) both are inherently low risk due to the vast experience of the AIS teammates identified to perform the work. MPAE/Zeiss lead the industry in the development of precision optics. University of Padua/Alenia will use their recent SAGE III

experience to ensure on time development of the scan/jitter control system and telescope integration and subsystem test. RAL/MSSL and UCB likewise have recent applicable experience developing and delivering CCD and ICCD camera systems for programs including STEREO/ SECCHI and HST.

E.11.1 Initial Schedule Development

At AIS project initiation, we will baseline the development schedule using the refined AIS Master schedule. We will use P3 software to track schedule and cost. Refinement of the initial AIS schedule will take the following steps: (1) the PM refines the AIS WBS (see Figure E11-1) used in generating the costs for this proposal based on the AIS contract requirements immediately after project initiation. (2) After review by the PSE and approval by the PI, the PM provides the WBS and the master schedule framework to the subsystem teams. (3) The subsystem managers develop detailed schedules with resource assignments using Microsoft Project, SureTrack, or P3. (4) These subsystem schedules are then integrated into the master schedule using P3. (5) The PM reviews the master schedule with the subsystem managers to eliminate inconsistencies and incompatibilities. (6) The PM and PI review and baseline the integrated AIS master schedule. (7) The PM then negotiates, allocates, and baselines cost to each WBS element.

The result of this process is a set of WBS budgets that will be linked to the SwRI cost reporting system at project initiation. The SwRI cost tracking system provides on-line costs that are available to the PM and his support personnel for daily cost tracking of SwRI costs, and monthly tracking of contributor and subcontractor costs. Using the real-time cost system allows the PM and the PI to quickly identify problems and to develop workarounds as needed.

E.11.2 Monthly Schedule Tracking

For the AIS project, our internal monthly scheduling process will include the following activities: (a) Instrument subsystem managers, will update their schedules to show actual work accomplished during the reporting period and will provide estimated dates of completion for tasks currently in work (rather than the less accurate percent complete). These managers will include a list of schedule changes and variances. (b) The updated subsystem schedules will be delivered to the PM at SwRI where he integrates the schedules into the P3 master schedule. (c) The PM will
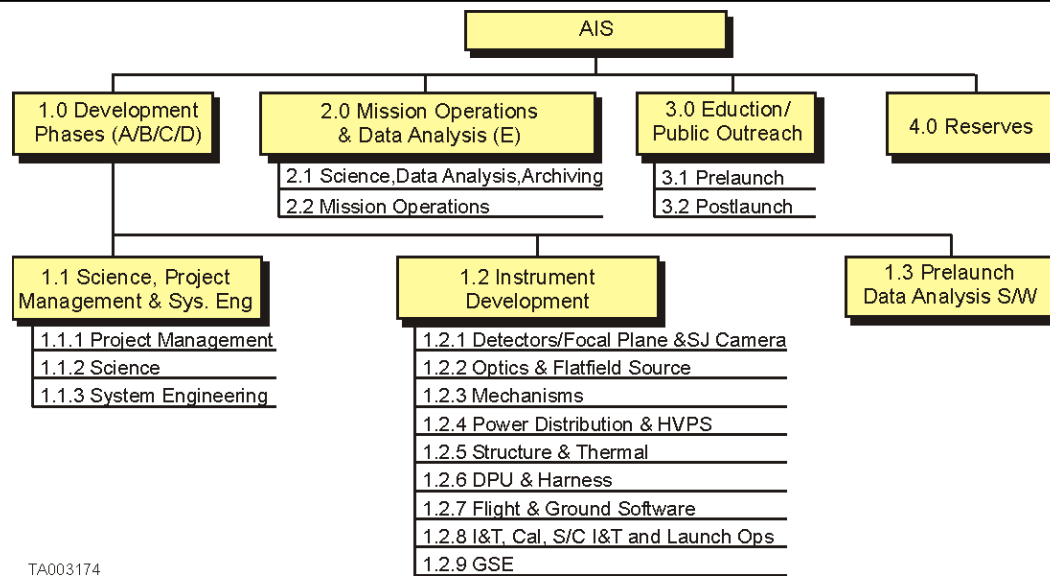
Figure E11-1. AIS Work Breakdown Structure

generate an updated master schedule containing the current and previous month's schedule, and delivers the new master back to the subsystem managers. (d) Schedule performance metrics will then be produced from the statused schedule showing the critical path, predecessor/successor linkages, and the current and any change in the total float for each task. (e) The PM will review the schedule metrics derived from the step above and the performance of each subsystem. (f) The PM will review the schedule performance metrics and make an honest assessment of possible future issues with each subsystem manager and take action when necessary. The result of this risk-reducing strategy is that small corrections are made early, rather than large corrections later.

A number of metrics are examined for diagnostics; the two most important of these are the total float and the change in the total float for each task. By looking at how the total float has changed, it is easy to determine what tasks are slipping (or being accomplished ahead of schedule). By plotting these values over several months, trends can be established and workarounds can be implemented if needed. This method is a modified way to look at schedule variance that is intuitively easier to discuss with subsystem managers than the more traditional definition of schedule variance (Budgeted Cost of Work Planned minus Budgeted Cost of Work Scheduled). Using schedule trends, the PM gains a clear picture of the AIS schedule performance. The master schedule is used to identify upcoming problems and more importantly, provides a tool

that will be used to perform "what if" workarounds that will solve schedule problems, thus reducing AIS schedule risk.

E.11.3 Monthly Cost Performance Tracking

The purpose of this function is to accurately control costs. This will be based on the P3 resource loaded schedule. The process for implementing and executing the earned value reports is as follows: (a) Just as the individual subsystem schedules are updated monthly by the subsystem managers, the actual cost incurred is also updated within the integrated subsystem schedules for US funded activities. (b) The updated subsystem schedules with updated actual costs will be delivered to the PM and then integrated into the P3 master schedule. (c) The PM then generates an updated master schedule that includes the AIS Budgeted Cost of Work Performed (BCWP) and the Actual Cost of Work Performed (ACWP). A negative BCWP minus ACWP indicates a potential cost problem, whereas a positive value shows that the work was performed for fewer resources than originally planned and budgeted. Negative values decrease the budget reserves while positive cost variance increases the cost reserves. (d) The PM reviews the budget metrics derived from the step above and the budget performance of each subsystem. And (e) the PM reviews the cost performance metrics with each of the subsystem managers, reports to the PI, and the team makes action plans as necessary.

Major subcontract incurred costs including UCB, COI, and the CoIs, will be input into P3 and treated just like SwRI internal costs. This will

allow true "project level" evaluation of the NASA funded costs to provide early warning of potential cost problems. It also allows the PM the insight into what subsystem is likely to need cost reserve help.

The cost metrics examined monthly by the PM will include BCWP, ACWP, Budgeted Cost of Work Scheduled (BCWS), and Estimate at Completion to quickly identify problems at the task level and ensure that the status of the project budget is known at all times.

E.11.4 Technology Development Plans and Back-up Plans

AIS is intentionally designed to minimize new technology development and to utilize existing flight proven processes, techniques and systems. The baseline design of AIS requires no new technologies. See Table A3-1 for a list of AIS subsystem heritage and Section D for a discussion on plans for AIS technology infusion and transfer.

E.12 Acquisition Strategy

SwRI, the PI institution, will serve as the prime contractor to NASA for the AIS instrument through a cost plus fixed fee (CPFF) contract. UCB and all CoI's will likewise have subcontracts though SwRI for CPFF or cost type contracts.

E.13 Risk Management Plan

Risk management is the process of systematically balancing cost, schedule and technical risk. Our highest priority in structuring the AIS program is to produce an investigation that meets the AIS science objectives at the lowest programmatic and technical risk. To obtain this goal we have chosen systems with extensive heritage, an integral screening and burn-in process, a rigorous environmental test program, a project-wide risk management system, institutions highly experienced in the development of space flight instrumentation, and a systems engineering program whose prime responsibility is to infuse risk minimization throughout the project.

The AIS management team will implement a risk management system for the purpose of identifying risks and mitigating their effects before they disrupt project activities. Risk management consists of three activities that will be continuously applied for the duration of the AIS project. These activities include 1) risk identification and analysis, 2) risk action planning, and 3) risk tracking and control. The PSE will lead the process of risk reduction. A RRT made up of the PSE, institutional SE's, the AIS Mission Assurance Lead, and PM will have biweekly telecons to address AIS risk reduction.

E.13.1 Risk Identification and Analysis

Risk identification will continue on a regular basis throughout the AIS project. The risks will be identified using all appropriate methods, including team reviews, independent audits, reliability analysis, team telecons, peer reviews, project risk questionnaires, and schedule tracking and analysis for monthly reports. Identified risks will be categorized into one of three categories: (1) performance risks; (2) technical resource risks (i.e. mass, power, telemetry, etc.); or (3) programmatic risks (i.e. schedule, budget, personnel availability, etc.). Following risk identification, we will analyze the probability (Lr-likelihood of risk) and impact (Cr-consequence of risk) of each risk to determine risk criticality. We will categorize the risk items by multiplying their likelihood value (1 to 3) by the consequence (1 to 3) to determine a risk factor. Risk factor likewise is categorized low (score of 1 to 3), medium (score of 4 to 6) or high (score of 7 to 9). Items with the highest risk factor will receive the most focus by being discussed on all weekly management and SE telecons. All risks will be discussed and statused on the RRT telecon and documented in the AIS Risk List.

E.13.2 Risk Action Planning

The RRT will assign an action plan to each identified risk. Actions are risk-mitigating activities that may include prototyping the system, early environmental testing, performing a feasibility study, performing a site visit to a vendor, adding project staff, etc. or accepting the risk. Action planning activity will occur whenever new risks are identified and will be conducted as follows: 1) Resources are assigned to the risks with the highest risk factor; 2) Triggering events are established which will cause action plans to be executed; 3) Retirement criteria are established for each risk; 4) Assign one of four types of actions (act immediately, transfer the action to another AIS team member, delegate internally within the RRT, or initiate further investigation); and 5) Enter each risk in the AIS Risk List.

E.13.3 Risk Tracking and Control

The RRT will have the primary responsibility for tracking and controlling the risks. Trigger events will be input into the AIS project schedule. As they become due, the RRT will asses the status of the risk by examining whether the retirement criteria has been met. If not, the RRT will assign a

new action to the risk with a new triggering event if needed. It will be the responsibility of the PSE to maintain the AIS Risk List.

E.13.4 Identified AIS Risks

AIS has deliberately been designed to minimize complexity and to take advantage of existing flight-proven hardware. Nonetheless, Table E13-1 lists the top four risk items to the AIS project based upon their risk factor with their potential implication and workaround.

E.13.5 Descopes

The 35% cost reserves we have provided in our budget, and the streamlined approach the team takes to accomplishing the AIS science objectives, reduces the probability of descopes. However, in the event that out of the ordinary problems happen during the course of the AIS project, the AIS team is prepared to present descope options to reduce cost, decrease schedule or reduce mass or power. As a result of the action planning efforts of the risk management system presented above and the monthly schedule and cost review, the AIS project will be proactive rather than reactive when dealing with descopes. The PI and PM will use our project status metrics system (§E.11), to monitor and track schedule, cost and development progress to be able to see where margins may be reduced to maximize the cost or schedule savings. Any descope of the investigation will require coordination and approval of the NASA SDO Project Office because the descope may increase risk, lower instrument performance, or affect science return. Table E13-2 outlines potential options for descoping.

F.   Cost/Cost Estimating Methodology

F.1   Initial Cost Development

Cost development for the AIS project included the following steps. (a) The master schedule and WBS were developed by the PM and passed to each subsystem manager. (b) Each manager was provided a set of documentation on items that could affect cost, such as environmental and parts requirements. (c) The managers filled in lower level details in the WBS and assigned resources (labor hours, parts cost, travel budget, facility usage cost, etc.) for each activity. (d) The subsystem managers gave their resource-loaded schedules back to the PM. (e) The PM obtained project support costs from internal SwRI personnel who will assist in the coordination and management of the AIS project. (f) The PM and PI obtained resource requirements from the science team, costs for E/PO, Technology Transfer, and costs for the other project support activities. (g) The PM and PI calculated the total project costs by summing the lower level WBS costs down to the levels as called for in AO Tables B1 and B3, as appropriate. Final WBS budgets were then frozen. This "bottoms-up" process of deriving project costs based on the project schedule ensured that all activities were accounted for in the budget process. This process also ensured ownership of the WBS budgets by the team members who will manage each sensor and subsystem budget.

Table E13-1. AIS Top 4 Risks				
AIS Risk	**Type of Risk**	**Implication / Mitigation**		**Risk Factor**
European partners unable to provide AIS subsystem due to funding problem	Programmatic Risk	Incomplete instrument / 1) Ensure level of effort from each partner is supported by their funding authority, 2) Off-load subsystem to other partner institution, 3) Bring work in-house, fund with cost reserves		Low
ICCD's late due to development problems	Programmatic risk	Schedule impact, potential cost impact/ 1) ICCD being developed by institutions (UCB/RAL/MSSL) experienced in delivering flight ICCD's, 2) have established single POC for ICCD, 3) Early funding of UCB		Low
Scan / jitter mechanism does not meet performance spec	Performance risk, Programmatic risk	Reduced instrument performance & potential schedule problem / 1) Alenia is experienced at developing flight mechanisms for optical systems (SAGE III), 2) U. of Padua will provide early funding to Alenia for early prototyping and test (vibe & life testing) of mechanism		Low
AIS grating does not meet performance spec	Performance risk, Programmatic risk	Reduced instrument performance & potential schedule problem / 1) JY is experienced optical fabricator, 2) IAS will provide early funding for prototyping of grating		Low

No.	Descope Option / Science Implication	Reason for Descope	Cost Savings at: PDR	Cost Savings at: CDR	Mass/Power Implications
1	Delete flat field lamp / Reduced calibration capability	Cost, schedule or mass savings	$300 k	$200 k	0.3 kg, minimal power change
2	Remove slit changer mechanism / Reduced in-flight capability	Cost, schedule or mass savings	$50 k*	$25 k*	1 kg, minimal power change
3	Reduce number of detectors from 3 to 2 / Reduced diagnostic capability	Cost, schedule mass, power savings	$300 k	$200 k	2 kg, 6 watts
4	Remove slit jaw camera / Reduced co-alignment capability	Cost, schedule, mass, power savings	$300 k	$200 k	0.9 kg, 6.4 watts
5	Make detector vacuum door a one shot open in flight/reduced photometric stability	Cost, schedule, mass savings	$200 k	$150 k	0.8 kg

Table E13-2. Prioritized List of Descope Options

* Minimal cost savings. Subsystem provided at no cost to NASA by European partner

F.2 Institutional Basis of Cost

SwRI: Using the WBS as a guide, the proposed costs were based upon detailed estimates of the labor and resource requirements for each WBS lower level elements. Costs for parts, travel, GSE, etc., were based upon vendor quotes, recent purchase orders, or catalog prices. Each subsystem manager developed a preliminary parts list and obtained costs for each activity and component ensuring cost estimating accuracy and future ownership of the estimate. Minimum buys were included when known and applicable. Travel quotes were based upon quoted air travel cost and government-approved per diem rates.

Costs for the AIS development is based upon the actual costs for several recently delivered flight programs including Swift, *Rosetta Alice*, IMAGE and Deep Impact. The AIS instrument development gains advantages from being able to use lessons learned during the IMAGE and *Rosetta* programs, and will use the UV calibration facility first used on *Rosetta Alice*.

Because of SwRI's long history of managing and developing flight hardware programs, there exists a large database of past history to be called upon when developing costs for a new program. The AIS science support, management, system engineering, mission assurance, flight software, E/PO (~1.5%) and technology transfer, spacecraft integration support, and launch operations support tasks were modeled on the effort and costs incurred for similar activities on past programs including IMAGE, NMP/DS1, Polar, UARS, *Rosetta*, and *Cassini*.

UCB: The UCB costs were likewise based on performance, labor required, and costs incurred on past missions and are tied to the UCB WBS. Parts costs are based upon written quotes from outside vendors or upon recent purchase orders. Labor hours were estimated directly from past UCB developments. Cost history and lessons learned from *Rosetta Alice* and HST/COS were directly used when estimating the UCB AIS costs.

Other: We based science team costs during the development phase on the effort required to achieve good team oversight and feedback. We have budgeted over 5 FTE for Phase B/C/D. E/PO costs were derived based on an analysis of our E/PO goals. MODA science is based upon the labor for 12 FTE lead scientists for the first two years of MODA and 4 FTE for the remaining 4 years of MODA.

F.3 AIS WBS Definition

As described earlier, the AIS WBS (Figure E11-1) was used as the foundation for developing the total AIS investigation cost.

The first element in the WBS (Table F-1) represents the costs for **Phase A**. This element includes all Phase A science, project management, system engineering, and instrument engineering costs. Costs for travel, CoI's and other Phase A expenses are also included in this WBS element.

WBS 1.0-Development represents the activities and costs associated with Phase B, and C/D of the AIS instrument development. **WBS 1.1–Science and Project Management** represents the activities associated with science and project management. The Project Management element (WBS 1.1.1) includes costs for the PI and the PM. The PI's activities are split between WBS 1.1.1 (Project Management) and WBS 1.1.2 Science. Also included in the Project Management WBS element are support personnel and all AIS travel to support reviews, vendor site visits, integration, CoI facility visits, SDO Project Office visits, science team meetings, and SDO SWG meetings. WBS 1.1.2 includes all science

activities. This WBS level includes ½ of the budgeted PI's time, as well as all U.S. funded CoI activities. The final element under the science and project management WBS is System Engineering (WBS 1.1.3) which includes activities such as the oversight of the development of the AIS Instrument Performance Specification, internal and external AIS ICDs, the system engineering requirements database, and oversight of the AIS verification test program. Performance assurance activities, safety, and parts and configuration control are also included in the System Engineering WBS element.

WBS 1.2 – Instrument Development represents the major development activities for the AIS project. ICCD detector and SJC activities, fall under WBS 1.2.1. UCB costs for the development of the AIS detector intensifiers is included in this element. Oversight of the detector and SJC by SwRI is also included. Contributed elements under WBS 1.2.1 include the contribution from the UK for all four CCD detectors and detector electronics at no cost to NASA. WBS 1.2.2 – Optics and Stim Source, captures the activities to develop the flat field stim source located internal to the AIS housing. All of the optics for AIS are being contributed by our European partners: IAS and MPAE are contributing the grating and telescope optics, respectively, at no cost to NASA. AIS mechanisms activities are included under WBS 1.2.3. The only mechanism being developed in the U.S. is the detector vacuum door, which is being provided by UCB, and is nearly identical to the flight qualified HST/COS door. All other mechanisms are being contributed by the University of Padua and MPAE. These mechanisms include the scan/jitter control system, slit changer mechanism, and front aperture door. The AIS power distribution activities (WBS 1.2.4) are the responsibility of SwRI. These activities include the development of the high voltage power supplies that provide the bias voltage for the ICCDs and the AIS low voltage dc/dc converters and distribution system. WBS 1.2.5 represents the activities for the development of the structure and thermal subsystems for AIS. Included in this activity is the cost of fabricating the graphite epoxy composite structure by COI. The design of all the mechanical systems *not* contributed by our European partners is also included in this activity. The AIS DPU and harness will be provided by SwRI; these activities are covered in WBS 1.2.6.

SwRI will develop all AIS flight software under WBS 1.2.7. The AIS estimate is very similar to other SwRI software programs of similar scope, including the NASA Swift, IMAGE, and Deep Impact programs. It is assumed that all AIS subsystems will have completed subsystem qualification testing prior to being integrated into the AIS instrument system. WBS 1.2.8 picks up after subsystem test and verification. It includes all activities associated with AIS instrument integration and test, instrument calibration, integration of AIS onto the SDO spacecraft, and support of SDO launch operations. This WBS element begins in FY04 and continues out through launch of the SDO plus 30 days and includes engineering costs during this time frame. WBS 1.2.9-GSE, represents the activities associated with the development of the mechanical and electrical GSE needed to support the AIS during the integration and test phase. Items including AIS stimulators, shipping containers, structural thermal model, electrical GSE, are included in this activity (MPAE is contributing the GSE software).

Due to the nature of the SDO mission and its large amount of data, we have budgeted a significant effort pre-launch to develop data analysis algorithms and to set up the architecture and infrastructure to be used during flight for scientific analysis and data pipelining. These activities all fall under **WBS 1.3–Pre-Launch Data Analysis Software**. This activity has the benefit of a very substantial contribution by the University of Oslo and IAS to develop data analysis, visualization, and quicklook software, as well as software and algorithms in preparation for the archiving of the AIS scientific data.

WBS 2.0-Mission Operations and Data Analysis includes all post launch activities (except for post launch E/PO). WBS 2.1 covers the Science, Data Analysis, and Archiving activities. WBS 2.2 – Post Launch Mission Operations, covers the activities for the day-to-day operations of running the AIS instrument. We based our estimate on the low level of required commanding needed for the AIS investigation and past experience with operations of the IMAGE observatory. As with the pre-launch activities, AIS has the benefit of a *significant* contribution by our European partners for science and data analysis.

WBS 3.0 – Education and Public Outreach, represents the activities associated with the AIS Education and Public Outreach Program, both pre-

launch and post-launch. We have budgeted 1.5% of the AIS budget throughout the program for these activities.

The final WBS, 4.0, covers the AIS budget reserves. As discussed in the following sections, we have allocated a healthy 35% reserve in excess of the AIS development cost. The AIS management team in consultation with the SDO project office will have access to this large amount of reserve to solve problems early and to reduce overall project risk.

F.4 Cost Reserves and Reserve Strategy

Just as our release of technical reserves is tied to the AIS schedule, our plan for release of cost reserves is structured to release reserves in a controlled manner through critical mission phases. Should the drain on reserves be greater than that shown in Figure F4-1, a descope action will be initiated unless a credible mitigation plan can be developed. It is our suggestion that some amount of the reserves be set-aside at the beginning of the project as a permanent lien to cover the cost of a modest launch slip caused by an event outside of the control of the AIS team. This initial lien will be negotiated with the SDO Project Office.
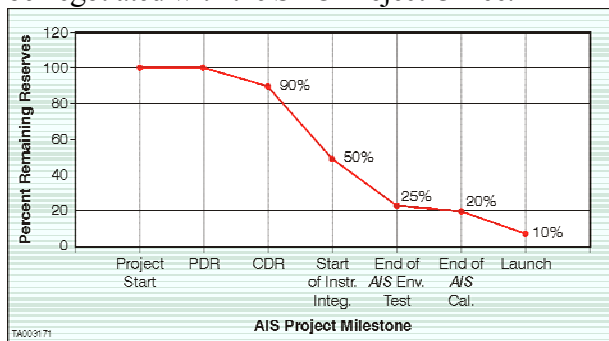
Figure F4-1. AIS Reserved Depletion Schedule

Our plan is to exit the AIS PDR with 100% of the reserves intact, then release approximately 10% of the reserves between PDR and CDR. Release of reserves in this time frame will be used for long lead part procurement, advanced prototyping and testing, and other activities designed to reduce risk later in the project. The timeframe between CDR and instrument integration is the most likely time for requests for release of reserves. Our plan is to release reserves as necessary to control risk but not to allow reserves to drop below 50% by instrument integration. AIS environmental test is the next most likely timeframe for liens on reserves. We plan to release reserves to a level of no less than 25% by the conclusion of AIS environmental test.

Instrument calibration, the final activity before AIS delivery, is traditionally less risky. We plan on releasing only 5% of reserves at that time leaving a minimum of 20% reserves remaining at the time of instrument delivery. We will pace ourselves to hold between 5-10% of reserves through launch to support last minute problems at the launch site and to accommodate an additional launch slip of approximately 4 months.

Release of reserves will be made by a consensus of the PM and PI with recommendation by the PSE. Outside US teams (i.e. UCB, US Co-I's) requesting reserves will do so through a process similar to an ECR, documenting the request and explaining the consequences to the project if the reserves are not released. The status of all AIS margins (e.g. mass, power, dollars) will be reported monthly to NASA.

F.5 AIS Cost

The proposed AIS mission was designed to fit within the stringent SDO payload cap and includes sufficient cost reserves to ensure on-schedule completion of the instrument within our proposed cost. The estimated cost of the mission is provided in Tables F-1, F-2, and F-3 (B-2, B-3A, and B-3B). Cost reserves of 35% on the US instrument costs, excluding science, Phase A, MODA and EPO costs, have been established to mitigate technical, schedule and cost risks. All schedule reserve is also costed to supply additional cost margin. Total NASA OSS Cost includes all phases and all elements that are to be funded by NASA. The substantial contributions include all phases and elements that are proposed to be provided to the AIS investigation at no cost to NASA.

We feel confident that the 35% ($3.3 M) reserves is adequate to ensure on-schedule completion of the instrument within our proposed cost. Unspent cost reserve will be used to augment funding of Science and E/PO,during Phase E – F.

F.5.1 Potential Cost Savings

The AIS budget includes full costs for a standalone AIS instrument DPU. Several SDO instruments have similar data processing and instrument interface requirements as AIS and as shown in §A.3.1.8, the AIS DPU currently has excess processor margin (100%). It is highly likely that a single Payload Data Processor could be provided that would service all of the SDO instruments at not much more cost than a single instrument DPU.

Table F-1 (Table B-2). Total Investigation Cost Funding Profile

(Costs by FY in Real-Year Dollars, Totals in Real-Year Dollars (RY$) and FY2002 K$)

Item			FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	Total (RY $)	Total (FY02$)
NASA Cost																
Phase A	(1)		110,094	770,421											$ 880,515	$ 871,722
Phase B/C/D																
WBS 1.0		Development														
WBS 1.1		Science and Project Management														
1.1.1		Project Management		172,655	339,574	324,614	220,708	95,370							$ 1,152,922	$ 1,071,065
1.1.2		Science		239,276	469,375	448,397	416,768	341,447							$ 1,915,262	$ 1,819,840
1.1.3		System Engineering		154,464	253,303	229,821	147,851	30,336							$ 815,776	$ 755,384
WBS 1.2		Instrument Development														
1.2.1		Detector / Focal Plane and SJ Camera		42,434	985,479	422,348									$ 1,450,261	$ 1,445,316
1.2.2		Optics and flat field source		42,434	41,163	8,431									$ 92,028	$ 87,083
1.2.3		Mechanisms		26,333	213,296	23,700									$ 263,329	$ 263,329
1.2.4		Power distribution		42,434	261,113	46,079									$ 349,626	$ 334,333
1.2.5		Structure and thermal		84,869	829,633	240,861									$ 1,155,363	$ 1,135,732
1.2.6		DPU and harness		84,869	758,886	252,962									$ 1,096,716	$ 1,069,220
1.2.7		Flight Software		42,434	318,487	171,493									$ 532,414	$ 503,806
1.2.8	(2)	Int / test / Cal / SC I&T / Launch ops		0	82,042	492,249	137,337	310,024							$ 1,021,652	$ 913,970
1.2.9		GSE		0	170,255	91,676									$ 261,930	$ 254,035
WBS 1.3		Prelaunch Data Analysis S/W			51,825	303,650	455,475	507,300							$ 1,318,250	$ 1,173,243
WBS 2.0		Science Operations and Data Analysis														
2.1		Post Launch Science, Data Analysis & Archive							86,635	1,029,246	998,493	617,896	622,381	628,447	590,760	$ 4,573,858	$ 3,970,733
2.2		Post Launch Mission Ops							8,359	93,944	96,574	99,278	102,058	96,173		$ 496,386	$ 398,740
WBS 3.0		E/PO														
3.1		Prelaunch		0	0	42,502	43,125								$ 85,627	$ 77,738
3.2		Post Launch						44,250	44,523	12,050	12,098	13,002	13,023	13,250	$ 152,196	$ 125,700
WBS 4.0	(3)	Reserves (35%)		760,552	760,552	830,552	713,441	257,110							$ 3,322,206	$ 3,051,635
Total NASA Cost			**$ 110,094**	**$ 2,463,175**	**$ 5,534,982**	**$ 3,929,335**	**$ 2,134,706**	**$ 1,680,830**	**$ 1,167,713**	**$ 1,107,117**	**$ 729,272**	**$ 737,441**	**$ 737,643**	**$ 604,010**	**$ 20,936,317**	**$ 19,322,623**
Contributions:																
WBS 1.0		Development														
WBS 1.1		Science and Project Management														
1.1.1		Project Management														
1.1.2		Science														
1.1.3		System Engineering														
WBS 1.2		Instrument Development														
1.2.1		Detector / Focal Plane and SJ Camera		$ 1,250,000	$ 1,500,000	$ 75,000	$ 75,000	$ 100,000							$ 3,000,000	$ 2,858,651
1.2.2		Optics and flat field+C7 source		$ 500,000	$ 750,000	$ 75,000	$ 75,000	$ 100,000							$ 1,500,000	$ 1,419,379
1.2.3		Mechanisms		$ 3,000,000	$ 4,000,000	$ 150,000	$ 150,000	$ 200,000							$ 7,500,000	$ 7,149,950
1.2.4		Power distribution														
1.2.5		Structure and thermal														
1.2.6		DPU and harness														
1.2.7		Software														
1.2.8		Int / test / Cal / SC I&T / Launch ops														
1.2.9		GSE		$ 500,000	$ 500,000										$ 1,000,000	$ 959,515
WBS 1.3		Prelaunch Data Analysis S/W			$ 1,000,000	$ 1,500,000	$ 1,500,000	$ 1,500,000							$ 5,500,000	$ 4,976,688
WBS 2.0		Science Operations and Data Analysis														
2.1	(3)	Post Launch Science, Data Analysis & Archive							$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 15,000,000	$ 11,874,974
2.2		Post Launch Mission Ops													$ -	$ -
Total Contributions			**$0**	**$5,250,000**	**$7,750,000**	**$1,800,000**	**$1,800,000**	**$1,900,000**	**$2,500,000**	**$2,500,000**	**$2,500,000**	**$2,500,000**	**$2,500,000**	**$2,500,000**	**$ 33,500,000**	**$ 29,239,157**

	Total Invest. Cost	$ 54,436,317	$ 48,561,780

Notes:
1) Phase A costs include all science, project management, system engineering, and instrument engineering costs for Phase A.
2) WBS 1.2.8 includes costs for instrument integration and test, calibration, spacecraft integration and test, and launch support.
3) Assumes constant funding for the AIS European Science Team throughout Phase E and F.

APPENDIX 1

Letters of Endorsement

APPENDIX 2

Resumes

APPENDIX 3

Statements of Commitment
and
Current and Pending Support

APPENDIX 4

Statement of Work

1.   Introduction

This Statement of Work (SOW) is submitted in response to the requirements of NASA AO-02-OSS-01, dated January 18, 2002. This SOW details the work to be performed by the Southwest Research Institute (SwRI) and its team members for the Phase A Concept Study (Phase A) portion of the Atmospheric Imaging Spectrograph (AIS) project for the Solar Dynamics Observatory (SDO) mission. A general description of tasks to be performed in subsequent project phases (B, C, D, E and F) is also provided. SwRI will be the sole contractor to NASA for AIS. All other AIS team members will be funded through subcontracts from SwRI. Memorandums of Understanding and Statements of Work between SwRI and the AIS Team members will be negotiated to support the tasks of this SOW.

2.   Period Of Performance

The concept study period consists of the period of time reserved for both Phase A and the Bridge Phase. Both shall be completed within 10 months of contract award.

3.   Scope Of Work

SwRI shall provide the personnel, equipment and facilities to perform all phases and aspects of the AIS project including: 1) life-cycle project management; 2) design, development, test, calibration, spacecraft integration, and flight operations of the AIS investigation); and 3) post-operations data analysis and archiving. SwRI shall directly manage all AIS project phases.

SwRI shall conduct the Phase A Concept Study in accordance with the "Guidelines and Criteria For The Concept Study". In this study, the AIS Team shall:

    A. Conduct trade and risk reduction studies with emphasis on:

        1. Optimization of the instrument (and mission) design to ensure efficient use of SDO resources (i.e. mass, power, telemetry, etc.) and to optimize science return.
        2. AIS measurement requirements.
        3. Technical approach.
        4. Instrument optics/pointing requirements.
        5. Optimization of the instrument data handling architecture.
        6. Spacecraft/instrument accommodation requirements.
        7. Optimization of the instrument design for reduced cost and minimum risk.
        8. Descope definition and cost savings quantification.

    B. Update and refine the existing project cost estimates and Cost Plan.
    C. Develop the Project Implementation Plan for Phase B/C/D/E/F.
    D. Refine the risk management plan and develop mitigation strategies.
    E. Outline the fabrication, integration, test, and operation of the system.
    F. Refine the Education, Public Outreach, Technology, and Small Disadvantaged Business Plans.
    G. Organize the AIS Performance Assurance Implementation Program (PAIP) for the project.
    H. Refine team member responsibilities and organizational structure.
    I. Document the results of the studies in the Phase A Concept Study Report.

4.   **Deliverables**
  A. The results of the study shall be summarized in a Phase A Concept Study Report, to be submitted at the conclusion of the Study Phase.
  B. All of the study documentation, plans, and reports produced during this period, although not required as deliverables, will be itemized in the Phase A Concept Study Report Appendix and will made available to NASA upon request.

5.   **Government Responsibilities**
No Government responsibilities are defined for the Concept Study phase.

6.   **General Statements Of Work For Phases B, C, D, E, and F**
The general tasks to be performed in follow-on AIS phases are outlined below. These tasks will be further defined in implementation plans produced during the Phase A Concept Study.

  A. Period of Performance

The period of performance for definition, design, and development (Phases B/C/D) will be from 1 March 2003 through 31 August 2007. Phase E will cover the period of 60 months starting 1 September 2007. Phase F will cover one additional year following Phase E.

  B. Scope of Work

During Phases B/C/D/E/F, the AIS Team will:

  1. Provide day-to-day management and coordination of the AIS project as delegated by the PI to the PM, including monitoring and reporting technical progress and financial status, implementing the risk management plan and conducting a Preliminary Design Review, Critical Design Review, Environmental Test Readiness Review, Pre-ship Readiness Review, and Flight Readiness Review.
  2. Baseline the science requirements and science analysis plan into an AIS Instrument Science Requirements document.
  3. Implement an approved Performance Assurance Implementation Plan.
  4. Implement a systems engineering function to verify performance specification compliance to the instrument science requirements.
  5. Design, fabricate, calibrate and test the instrument, and integrate the instrument with the spacecraft.
  6. Perform AIS on-orbit commissioning, perform data acquisition for the instrument, and perform instrument operations during the SDO mission life.
  7. Implement education program activities, public awareness, small disadvantaged business participation in the project and pursue the transfer of new technology.
  8. Provide the services of the AIS Science Operations and Data Analysis Center and conduct instrument operations and data dissemination during Phase E.
  9. Analyze the AIS science data and report scientific results.
  10. Deliver the science data in proper formats to the appropriate NASA archives.

C. Reviews

The AIS Team shall conduct the following reviews not later than:

Milestone	Date
AIS Preliminary Design Review (PDR)	September 2003
AIS Critical Design Review (CDR)	April 2004
AIS Pre-Environmental Test Review (PER)	September 2005
AIS Pre-Ship Review (PSR)	April 2006
AIS Delivery to Spacecraft	June 2006

D. Deliverables

Mission Elements	
Item	**Date**
AIS instrument and associated EGSE/MGSE	June 2006
Science Data	As required
Data Items	
Progress Reports	Monthly
Financial 533M Reports	Monthly
Schedules	Monthly
AIS Instrument Science Requirements Document	December 2002
Performance Assurance Implementation Plan	December 2002
AIS Verification Plan/Procedures	PER – 60 days
Safety Assessment Report	PER
AIS Acceptance Data Package	Instrument delivery to s/c

E. Government Services

No government services will be required for AIS other than the CoI support as detailed in section A.3 of the AIS proposal.

APPENDIX 5

**Technical Content of Any
International Agreements**

1. Introduction

1.1 Background

The Southwest Research Institute is leading a team of US and European institutions in the investigation to quantitatively understand the physical mechanisms of energy transport in the outer solar atmosphere. This investigation includes modeling as well as the development of the Atmospheric Imaging Spectrograph (AIS), a solar spectrograph that will make EUV measurements, spectrally and spatially, at an unprecedented time cadence of the Sun's coronal region as part of the NASA Solar Dynamics Observatory (SDO) mission. The Principal Investigator of the AIS project, Dr. Don Hassler, has chosen to accept the offers of assistance in the implementation of the AIS project from the Max Planck Institut fur Aeronomie (MPAE) of Lindau, Germany; the University of Oslo, Norway; the Rutherford Appleton Laboratory (RAL) and Mullard Space Sciences Laboratory (MSSL) of England; the University of Padua, Italy; and the Institut d'Astrophysique Spatiale (IAS) of Orsay, France. Each of these institutions has unique expertise, facilities and experience in the development of space flight instrumentation and data analysis that will be of vital assistance to Dr. Hassler in the successful implementation of the AIS project.

1.2 Scope and Purpose of Document

This document defines the roles and responsibilities of the US, German, Norwegian, English, Italian and French research teams in the implementation of the AIS project. The work described in this document is being proposed to NASA in response to the NASA Solar Dynamics Observatory (SDO) Announcement of Opportunity AO 02-OSS-01.

2. Responsibilities of US and German Team Members

2.1 German Responsibilities - MPAE

MPAE will provide the following services and products in support of the AIS project:

- Assist in the science requirements definition of the AIS project.
- Assist in the optical design of the AIS.
- Specification development for the optical elements needed in the AIS.
- Specification development of the slit changer needed in the AIS.
- Fabrication and test of selected optical components (currently baselined as only the telescope optics) as agreed upon with US team members during Phase A of the AIS project.
- Fabrication and test of the slit changer in the AIS.
- Fabrication and test of AIS instrument door.
- Development of the AIS GSE software.
- Provide calibrated UV Lamp Source transfer standard for absolute radiometric calibration of the AIS instrument.
- Oversight of any German contractors employed to assist MPAE in their duties.
- Support assembly and subsequent calibration and environmental testing of AIS.
- Support the integration of the AIS with the SDO spacecraft.
- Support flight operations.
- Support anomaly resolution of problems.
- Assist in the design of observing scenarios.

- Support AIS Science Team meetings.
- Support data analysis, science and publication activities for data acquired from AIS and other SDO instruments.

2.2 US Responsibilities to MPAE

US team members will perform the following duties related to the US/ MPAE Germany joint instrument development.

- Develop optical system and optical component performance and environmental specifications.
- Develop AIS instrument performance and environmental test specifications.
- Develop optics to instrument ICDs.
- Develop slit changer to instrument ICDs.
- Develop AIS instrument door ICDs.
- Develop GSE software requirements specification and interface.
- Develop AIS to spacecraft ICDs.
- Provide telemetry and telecommand definition to MPAE.
- Develop detailed schedules for the work to be performed in Germany by MPAE.
- Provide all SDO mission unique quality assurance requirements to MPAE.
- Monitor the schedule performance of MPAE team members and take corrective action if schedule problems develop.
- Review MPAE plans and ensure compliance with SDO project quality management requirements.

3. Responsibilities of US and Norwegian Team Members

3.1 Norwegian Responsibilities

In support of the AIS project, the University of Oslo, Norway will provide data reduction, analysis and visualization software according to the following assumptions. Data reduction and analysis software falls into two categories: scientific end-user utilities such as interactive data browsers and configurable automatic mini-pipelines for handling particular data sets in a controlled batch mode; and the main data pipeline that reduces AIS raw telemetry into calibrated, archived, and cataloged data products. The University of Oslo takes primary responsibility for the suite of end-user utilities and contributes significantly to the development of the data pipeline. Specific modules that the University of Oslo will develop for the data pipeline include spatial data product assembly, line fitting, spectral calibration, and event detection.

In support of the AIS project, the University of Oslo, Norway will perform the following duties in the science support of the SDO mission.

- Participate in the science requirements definition of the AIS project.
- Lead in the development of the data analysis algorithms and software.
- Participate in data product selection, design, and format.
- Develop spatial alignment and spectral calibration algorithms for the data pipeline.
- Develop event identification algorithms and modules for the data pipeline.
- Develop interactive visualization and quicklook software.

- Develop configurable non-interactive reduction software for specific scientific tasks.
- Provide data analysis of AIS instrument data.
- Assist in the design of observing scenarios.
- Support AIS Science Team meetings.
- Support science and publication activities for data acquired from AIS.

3.2   US Responsibilities to Norway
US team members will perform the following duties related to the US/ Norway AIS project:

- Oversee the development of the AIS flight and ground system.
- Develop data visulaization and analysis software interface definition.
- Provide AIS instrument calibration values and algorithms to Norway.
- Provide AIS telemetry definition to Norway.
- Develop detailed schedules for the work to be performed in Norway by the University of Oslo.
- Monitor the schedule performance of Oslo team members and take corrective action if schedule problems develop.

4.   Responsibilities of US and UK Team Members

4.1   UK Responsibilities – RAL/MSSL
RAL and MSSL will provide the following services and products in support of the AIS project:

- Assist in the optical design of the AIS instrument.
- Assist in the specification development for the CCD and CCD electronics needed in the AIS.
- Fabrication and test of the CCD cameras and camera electronics for the AIS as agreed upon with US team members during Phase A of the AIS project.
- Oversight of any UK contractors employed to assist RAL/MSSL.
- Support the assembly and subsequent calibration and environmental testing of the AIS Intensified CCD cameras and the AIS instrument.
- Support in the integration of the CCD's with the intensifier stages.
- Support in the integration of the ICCD's with the AIS instrument.
- Support with the flight operations of the AIS.
- Support with anomaly resolution of problems.
- Support AIS Science Team meetings.
- Support data analysis, science and publication activities for data acquired from AIS.

4.2   US Responsibilities to RAL/MSSL
US team members will perform the following duties related to the RAL/MSSL UK joint instrument development:

- Develop optical system and optical component performance and environmental specifications for the AIS.
- Develop the AIS instrument performance and environmental test specifications.
- Develop the AIS detector-to-intensified CCD ICD.

- Develop the AIS ICCD to instrument ICD.
- Develop the ICD for the interface between the CCDs and intensifier stages.
- Develop detailed schedules for the work to be performed in the UK by RAL/MSSL.
- Provide all SDO mission unique quality assurance requirements to RAL/MSSL.
- Monitor the schedule performance of RAL/MSSL and take corrective action if schedule problems develop.
- Review RAL/MSSL plans and ensure compliance with SDO project quality management requirements.

5.   Responsibilities of US and Italian Team Members

5.1   Italian Responsibilities

In support of the AIS project, the University of Padua, Italy will perform the following duties in the support of the SDO mission.

- Participate in the science requirements definition of the AIS project.
- Participate in the optical design of the AIS.
- Assist in the specification development for the optical elements needed in the AIS.
- Assist in the specification development of the scan / jitter control system needed in the AIS.
- Fabrication and test of the scan jitter / control system as agreed upon with US team members during Phase A of the AIS project.
- Oversight of any Italian contractors employed to assist the University of Padua in their duties.
- Integration and test of the AIS telescope optics with the scan / jitter control system.
- Support to the US team in the assembly and subsequent calibration and environmental testing of the AIS.
- Support with the flight operations of the AIS.
- Support with anomaly resolution of problems.
- Support AIS Science Team meetings.
- Support data analysis, science and publication activities for data acquired from AIS.

5.2   US Responsibilities to Italy

US team members will perform the following duties related to the US/ Italy AIS project.

- Develop optical system and optical component performance (including scan / jitter control) and environmental specifications.
- Develop AIS instrument performance and environmental test specifications.
- Develop scan / jitter control system to instrument ICDs.
- Develop AIS to spacecraft ICDs.
- Develop detailed schedules for the work to be performed in Italy by the University of Padua.
- Provide all SDO mission unique quality assurance requirements to the University of Padua.
- Monitor the schedule performance of the University of Padua and take corrective action if schedule problems develop.

- Review the University of Padua plans and ensure compliance with SDO project quality management requirements.

6. Responsibilities of US and French Team Members

6.1 French Responsibilities

In support of the AIS project, the Institut d'Astrophysique Spatiale (IAS) of Orsay, France will perform the following duties:

- Participate in the science requirements definition of the AIS project.
- Participate in the optical design of the AIS.
- Assist in the specification development of the grating needed in the AIS.
- Fabrication and test of the grating as agreed upon with US team members during Phase A of the AIS project.
- Oversight of any French contractors employed to assist the IAS in their duties.
- Support to the US team in the assembly and subsequent calibration and environmental testing of the AIS.
-
- Participate in the archive design (catalog and user interface).
- Development of the archive software user interface.
- Support of data archiving for the European science partners.
- Support with the flight operations of the AIS.
- Support with anomaly resolution of problems.
- Support in data analysis, science and publication activities for data acquired from the AIS instruments.
- Assist in the design of observing scenarios.

6.2 US Responsibilities to France

US team members will perform the following duties related to the US/ France AIS project.

- Oversee the development of the AIS flight and ground system.
- Develop optical system and optical component performance and environmental specifications.
- Develop grating to instrument ICD.
- Develop archiving and database software specifications and ICD.
- Develop detailed schedules for the work to be performed in France by IAS.
- Provide all SDO mission unique quality assurance requirements to IAS.
- Monitor the schedule performance of IAS and take corrective action if schedule problems develop.
- Review the IAS plans and ensure compliance with SDO project quality management requirements.
- Provide telemetry definition to France.
- Provide AIS instrument calibration values and algorithms to France.

APPENDIX 6

Discussion on Compliance with U.S. Export Laws and Regulations

1. Introduction

The proposed Atmospheric Imaging Spectrograph (AIS) project benefits significantly from the support provided by international partners. Specifically, the support provided by the Max Planck Institut fur Aeronomie (MPAE) of Lindau, Germany; the University of Oslo, Norway; the Institut d'Astrophysique Spatiale (IAS) of Orsay, France; Rutherford Appleton Laboratories (RAL) and Mullard Space Sciences Laboratory (MSSL) of England; and the University of Padua, Italy are vital to mission success. The AIS team is very familiar with the requirements of the International Traffic in Arms Regulations (ITAR) law as well as the spacecraft items list in Chapter XV of the U.S. Munitions List (USML). AIS lead team member SwRI will be responsible for coordinating the development of all required Technical Assistance Agreements (TAA) needed to comply with the ITAR regarding the support to the instrument provided by Germany, Norway, France, England, and Italy.

In the following paragraphs, we describe our plans for complying with the Code of Federal Regulations, Title 22, Chapter I, Part 120 (CFR 129), International Traffic in Arms Regulation, which authorizes the President of the U.S. to control the export of defense sensitive technologies. Defense sensitive technologies are identified in the U.S. Munitions List, 22 CFR121 of Title 22, Volume I of the Code of Federal Regulation. Our team is highly experienced in laws and regulations contained in CFR 120-130 and the specific export of sensitive items identified in 22CFR121 having developed hundreds of TAAs for various SwRI projects and most recently TAA's for the NASA IMAGE mission as well as the Rosetta and Mars Express missions.

It should also be noted that in the current AIS development plan, no hardware is planned to be exported. As described in the following paragraph, a substantial amount of the AIS subsystems will be developed by our European partners and will ultimately be imported into the US. The proper licenses will be applied for should the need arise for the temporary export of any AIS hardware.

2. AIS International Partners

2.1 German Support

The Max Planck Institut für Aeronomie (MPAE) of Lindau, Germany will provide to the AIS project the UV spectrograph telescope optics, slit changer mechanism, aperture door, and GSE software. They will also be providing science and operations support to the AIS project during the SDO mission. Their technical expertise, resources and experience make the MPAE team a highly sought after team member for many NASA missions such as SDO.

To perform their work the MPAE team will need UV spectrograph interface information, performance assurance requirements, optical prescriptions, AIS telemetry and telecommand definitions, AIS test and flight environments, and will need access to the AIS telemetry stream to verify performance of their optical design as well as for scientific data analysis.

The Application for Technical Assistance (TAA) for German activities is currently in the signature process and will be submitted by May 24, 2002 (the required date for Letters of Endorsement for Non-U.S Proposers). Assuming a 3-month response time for the TAA approval, the TAA should be approved prior to project award to support detailed design discussions from the time of project initiation. (See a copy of the TAA following this appendix).

2.2   Norwegian Support

The University of Oslo will provide data analysis, visualization, and quicklook software as well as science support for the AIS project. They will not be providing any hardware to the program. To perform their work they will need AIS telemetry and telecommand definition, access to the AIS telemetry stream for scientific analysis, and will need to participate in operations planning.

The Application for Technical Assistance (TAA) for Norwegian activities is currently in the signature process and will be submitted by May 24, 2002 (the required date for Letters of Endorsement for Non-U.S Proposers). Assuming a 3-month response time, the TAA should be approved prior to project award to support detailed design discussions from the time of project initiation. (See a copy of the TAA following this appendix).

2.3   French Support

The Institut d'Astrophysique Spatiale (IAS) of Orsay, France will be providing the AIS grating and European archiving of AIS scientific data, as well as software and algorithms for data archiving. They will also provide science support for the AIS project. They   To perform their work, the IAS team will need UV spectrograph interface information, performance assurance requirements, optical prescriptions, AIS test and flight environments, and will need access to the AIS telemetry stream to verify performance of their optical design as well as for scientific data analysis.

The Application for Technical Assistance (TAA) for French activities is currently in the signature process and will be submitted by May 24, 2002 (the required date for Letters of Endorsement for Non-U.S Proposers). Assuming a 3-month response time, the TAA should be approved prior to project award to support detailed design discussions from the time of project initiation. (See a copy of the TAA following this appendix).

2.4   UK Support

The Rutherford Appleton Laboratories (RAL) and Mullard Space Sciences (MSSL) will provide to the AIS project the CCD cameras and camera electronics for the AIS spectrograph and the slit jaw camera. They have developed similar hardware for other space missions. They will also support the mission operations and data analysis (MODA) phase of the SDO mission.

The RAL/MSSL team will need UV spectrograph interface information, AIS performance assurance requirements, optical prescriptions, AIS test and flight environments, and will need access to the AIS telemetry stream to verify performance of their CCD cameras as well as for scientific data analysis.

The Application for Technical Assistance (TAA) for UK activities is currently in the signature process and will be submitted by May 24, 2002 (the required date for Letters of Endorsement for Non-U.S Proposers). Assuming a 3-month response time, the TAA should be approved prior to project award to support detailed design discussions from the time of project initiation. (See a copy of the TAA following this appendix).

2.5   Italian Support

The University of Padua, Italy will provide to the AIS project the scan and jitter control system for the AIS telescope. They will also be responsible for the integration and test of the telescope optics to the scan and jitter control system. Their team has developed a similar system for the

ISS SAGE III experiment. They will also be participating in data analysis and operations support during the MODA phase.

To perform their work, the University of Padua will need UV spectrograph interface information, performance assurance requirements, optical prescriptions, AIS test and flight environments, and will need access to the AIS telemetry stream to verify performance of their telescope systems as well as for scientific data analysis.

The Application for Technical Assistance (TAA) for Italian activities is currently in the signature process and will be submitted by May 24, 2002 (the required date for Letters of Endorsement for Non-U.S Proposers). Assuming a 3-month response time, the TAA should be approved prior to project award to support detailed design discussions from the time of project initiation. (See a copy of the TAA following this appendix).

3. Compliance with 22 CFR 120-130

3.1 Technical Assistance Agreements (TAA)

The AIS team is familiar with the process of preparing and submitting an application for Technical Assistance Agreement (TAA) for unclassified data in accordance with the CFR 125.2, license for export of data items. The TAA's have all been prepared and are currently in the signature process. SwRI will be responsible for following through on the submission and approval of the TAA and the subsequent development and implementation of the required Technology Export Control Plan (TECP).

3.2 Technology Export Control Plans (TECP)

Once a TAA is approved it will be necessary to develop and implement a TECP to ensure that any export sensitive technical data items are protected from willful or unintentional distributions to foreign persons. SwRI will be responsible for the development and implementation of TECPs required as provisions to the approved TAAs.

3.3 Memorandum of Understanding (MOU)

An MOU will be needed between the US and German, English, Italian and French governments to cover the import and export of goods between the two nations. We will initiate the process during Phase A by supplying a draft MOU to our European teammates for their routing through their government officials to obtain their concurrence. We will then supply NASA with the proper information to begin the process of finalizing the MOU. We are assuming that the entire process will take 12-months which is well within the timeframe needed for the receipt of overseas AIS hardware. Appendix 7 lists the details of the agreements that will be included in the MOU's.

Appendix 7

Description of Team Member Selection (NASA PI's Only)

(Not Applicable)

APPENDIX 8

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APPENDIX 9

Acronym List

ACWP   Actual Cost of Work Performed
ADAS   Atomic Data and Analysis Structure
AIA   Atmospheric Imaging Assembly
AIMS   Action Item Management System
AIRO   American Indian Research Organization
AIS   Atmospheric Imaging Spectrograph
ANSI   American National Standards Institute
AO   Announcement of Opportunity
AR   Active Region
ASAP   Advanced Systems Analysis Program
ASCE   Advanced Spectroscopic and Coronagraphic Explorer
ASDC   Advanced Solar Disk Spectrometer
ASIC   Application Specific Integrated Circuit
ASIST   Advanced System for Integration and Spacecraft Testing
ATWG   Analysis Tools Working Group
AU   Astronomical Unit
AXAF   Advanced X-Ray Astrophysical Facility
BATSE   Burst and Transient Source Experiment
BCS   Bragg Crystal Spectrometer
BCWP   Budgeted Cost of Work Performed
BCWS   Budgeted Costs of Work Scheduled
BESSY   Berliner Elektronenspeicherring-Gesellschaft für
            Synchrotronstrahlung
C&DH   Command and Data Handling
C/D or C,D Critical Hardware Phase
CAPS   *Cassini* Plasma Spectrometer
CASA   Center for Astrophysics and Space Astronomy
CBE   Current Best Estimate
CCD   Charge-Coupled Device
CCSDS   Consultative Committee for Space Data Systems
CDR   Critical Design Review
CDS   Coronal Diagnostic Spectrometer
CIM   Camera Interface Module
CIR   Corotating Interaction Region
CME   Coronal Mass Ejection
CMM   Capability Maturity Model
Co-I   Co-Investigator
COI   Composite Optics, Inc.
COS   Cosmic Origins Spectrograph
CP   Cost Plus
cPCI   Compact Peripheral Component Interconnect
CPFF   Cost Plus Fixed Fee

CPM	Central Processor Module
CPU	Central Processing Unit
Cr	Consequence of risk
CR/NAR	Confirmation Review/Non-Advocate Review
CTE	Coefficient of Thermal Expansion
CU	Colorado University
CVCM	Collected Volatile Condensable Material
DATM	Data Analysis, Theory, and Modeling
DPA	Destructive Parts Analysis
DPM	Deputy Project Manager
DPU	Data Processing Unit
DPWG	Data Products Working Group
DS-1	Deep Space 1
E/PO	Education/Public Outreach
EAC	European Analysis Center
ECO	Engineering Change Order
ECR	Engineering Change Request
EEE	Electrical, Electronics, and Electromechanical
EEPROM	Electrically Erasable Programmable Read-Only Memory
EFL	Effective Focal Length
EGSE	Electrical Ground Support Equipment
EIS	EUV Imaging Spectrometer
EIT	Extreme Ultraviolet Imaging Telescope
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPC	European Project Coordinator
ESA	European Space Agency
EUV	Extreme Ultraviolet
EUVS	Extreme Ultraviolet Spectrograph Sounding Rocket
FED STD	Federal Standard
FFT	Full Functional Test
FIP	First Ionization Potential
FITS	Flexible Image Transport System
FM	Flight Model
FMEA	Failure Modes Effects Analysis
FMECA	Failure Modes Criticality Analysis
FOR	Flight Operations Review
FOV	Field-of-View
FRR	Flight Readiness Review
FS	Field Stop
FSW	Flight Software
FTA	Fault Tree Analysis

FTE	Full-Time Equivalents
FUSE	Far Ultraviolet Spectroscopic Explorer
FUV	Far Ultraviolet
FUV-SI	Far Ultraviolet Spectrographic Imager
FUV-WIC	Far Ultraviolet Wide Field Imaging Camera
FWHM	Full Width at Half Maximum
GBM	GLAST Burst Monitor
GEMS	Great Explorations in Math and Science
GI	Guest Investigator
GIDEP	Government-Industry Data Exchange Program
GLAST	Gamma Ray Large Area Space Telescope
GN2	Gaseous Nitrogen
GOES	Geostationary Operational Environmental Satellite
GPIOM	General Purpose I/O Module
GRL	Geophysics Research Laboratory
GSE	Ground Support Equipment
GSEOS	Ground Support Equipment Operating System
GSFC	Goddard Space Flight Center
GUI	Graphical User Interface
HAO	High Altitude Observatory
HBCU	Historically Black Colleges and Universities
HMI	Helioseismic and Magnetic Imager
HRTS	High Resolution Telescope and Spectrograph
HST	*Hubble* Space Telescope
HVPS	High-Voltage Power Supply
H/W	Hardware
HXR	Hard X-ray
I&T	Integration and Test
I/O	Input/Output
IAS	Institut d'Astrophysique Spatiale
ICCD	Intensified Charged Coupled Device
ICD	Interface Control Document
ICR	Initial Confirmation Review
IDL	Interactive Data Language
IEEE	Institute of Electrical and Electronics Engineers
IES	Ion-Electron Spectrometer
ILWS	International Living with a Star
IMAGE	Imager for Magnetopause-to Aurora Global Exploration
IMF	Interplanetary Magnetic Field
IPS	Instrument Performance Specification
ITAR	International Traffic in Arms Regulations
ITOS	Integrated Test and Operations System
IUE	International Ultraviolet Explorer

JY	Jobin Yvon
LASCO	Large Angle and Spectrometric Coronagraph Experiment
LAT	Limited Angle Torque
LEO	Low Earth Orbit
LET	Linear Energy Transfer
LMSAL	Lockheed Martin Solar and Astrophysics Laboratory
LOS	Line of Sight
Lr	Likelihood of risk
LRR	Launch Readiness Review
LTE	Local Thermodynamic Equilibrium
LVDS	Low Voltage Differential Signal
LVPS	Low Voltage Power Supply
MAR	Mission Assurance Requirements
MCE	Mirror Control Electronics
MCM	Mirror Control Mechanisms
MCP	Microchannel Plate
MDI	Michelson Doppler Imager
MEI	Minority Education Institutions
MENA	Medium Energy Neutral Atom
MESSENGER	Mercury Surface, Space Environment, Geochemistry, and Ranging
MFLOP	Mega Floating-Point Operations per Second
MGSE	Mechanical Ground Support Equipment
MHD	Magnetohydrodynamic
MIDEX	Medium Class Explorer
MIP	Million Instructions per Second
MOA	Memorandums of Agreement
MOC	Missions Operation Center
MODA	Mission Operations-Data Analysis
MOR	Mission Operations Review
MOT	Management Oversight Team
MOU	Memorandums of Understanding
MPAE	Max-Planck-Institut für Aeronomie
MRR	Mission Readiness Review
MSSL	Mullard Space Science Laboratory
MSSTA	Multi-Spectral Solar Telescope Array
MSU	Montana State University
MTF	Modulation Transfer Function
NASA	National Aeronautics and Space Administration
NCAR	National Center of Atmospheric Research
NIAT	NASA Integrated Action Team
NIST	National Institute of Standards and Technology
NIXT	Normal Incidence X-ray Telescope
NMP/DS1	New Millennium Program / Deep Space 1
NOAA	National Oceanic and Atmospheric Administration

NSF	National Science Foundation
OASIS	Open Architecture Security Integration System
OPP	Operating Polices and Procedures
OSO	Orbiting Solar Observatory
OSS	Office of Space Science
P3	Primavera Project Planner
PCB	Parts Control Board
PDL	Perl Data Language
PDR	Preliminary Design Review
PEM	Particle Environment Monitor
PEPE	Plasma Experiment for Planetary Exploration
PERSI	Pluto Express Remote Sensing Investigation
PI	Principal Investigator
PM	Project Manager
PRA	Probabilistic Risk Assessment
PRD	Partial Frequency Redistribution
PROM	Programmable Read-Only Memory
PSE	Project System Engineer
PSF	Point Spread Function
PSR	Pre-Ship Review
PT	Prototype
PTB	Physikalisch-Technische Bundesanstalt
PZT	Piezoelectric Transducers
QE	Quantum Efficiency
RAL	Rutherford Appleton Laboratory
RDM	Radiation Dose Margin
RETMS	Real-Time Executive for Multiprocessor Systems
RHESSI	Ramaty High Energy Solar Spectroscopic Imager
RISE	Research Internships in Science and Engineering
RMS	Root Mean Square
RRT	Risk Reduction Team
RTEMS	Real-Time Executive for Multiprocessor Systems
S/C	Spacecraft
S/W	Software
SA	San Antonio
SAGE	Stratospheric Aerosol and Gas Experiment
SDAC	Solar Data Analysis Center
SDB	Small Disadvantaged Business
SDO	Solar Dynamics Observatory
SDT	Science Definition Team
SE	System Engineering
SEC	Sun-Earth Connection
SECCHI	Sun Earth Connection Coronal and Heliospheric Investigation

SECEF	Sun-Earth Connection Education Forum
SEI	Software Engineering Institute
SEL	Single Event Latchup
SEPAC	Space Experiment with Particle Accelerator
SERTS	Solar EUV Rocket Telescope Spectrometer
SEU	Single Event Upset
SIE	Spectrometer for Irradiance in the Extreme Ultraviolet
SIRTF	Space Infrared Telescope Facility
SJC	Slit Jaw Camera
SMM	Solar Maximum Mission
SOC	Science Operations Center
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
Solar-B/EIS	Solar-B/EUV Imaging Spectrometer
SORCE	Solar Radiation and Climate Experiment
Sp	Spare (flight)
SPARC	Scalable Processor Architecture
SPM	Solar Probe Mission
SRAM	Static Random Access Memory
SRR	Systems Requirements Review
STEREO	Solar TErrestrial RElations Observatory
STIS	Space Telescope Imaging Spectrograph
STM	Structural Thermal Model
SUMER	Solar Ultraviolet Measurements of Emitted Radiation
SVLS	Spherical Variable-Line Space
SWG	Science Working Group
SWHM	Small Disadvantaged, Woman-Owned, Hispanic Historically Black Colleges and Minority Institutions
SwRI	Southwest Research Institute
SXT	Soft X-ray Telescope
TAA	Technical Assistance Agreements
TB	Thermal Balance
TECP	Technology Export Control Plans
TID	Total Integrated Dose
TML	Total Mass Loss
TRACE	Transition Region and Coronal Explorer
TVAC	Thermal Vacuum
TXI	Tunable X-ray Imager
UARS	Upper Atmosphere Research Satellite
UART	Universal Asynchronous Receiver-Transmitter
UCB	University of California at Berkeley
UV	Ultraviolet
UVCS	Ultraviolet Coronagraph Spectrometer

UVOT	Ultraviolet and Optical Telescope (Swift)
UVSP	Ultraviolet Spectrometer and Polarimeter
VDC	Volts Direct Current
VLS	Variable Line Space
WBS	Work Breakdown Structure
WCA	Worst Case Analysis
WCI	White-Light Coronagraphic Imager
WG	Working Group
WOSB	Women-owned Small Business
XDL	Crossed Delay-Line
XRT	X-Ray Telescope (Swift)
XUV	Extreme Ultraviolet
YPOP	Yohkoh Public Outreach Project